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Potential Radiological Impact of Tornadoes on the Safety of Nuclear Fuel Services' West Valley Fuel Reprocessing Plant

Tornado Effects on Head-end Cell Airflow

Prepared by L. J. Holloway, R. W. Andrae

Oak Ridge National Laboratory

Prepared for
U.S. Nuclear Regulatory
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Environmental Radiological Impact of Fukushima on the Safety of The Food and the Water Valley The Fukushima Region

Report of the Fukushima Prefecture

The Fukushima Prefecture is a coastal prefecture in the Tohoku region of Japan. It is known for its beautiful scenery, including the famous Fukushima Five-Color River. The prefecture is also known for its agricultural products, such as Fukushima apples and Fukushima rice.

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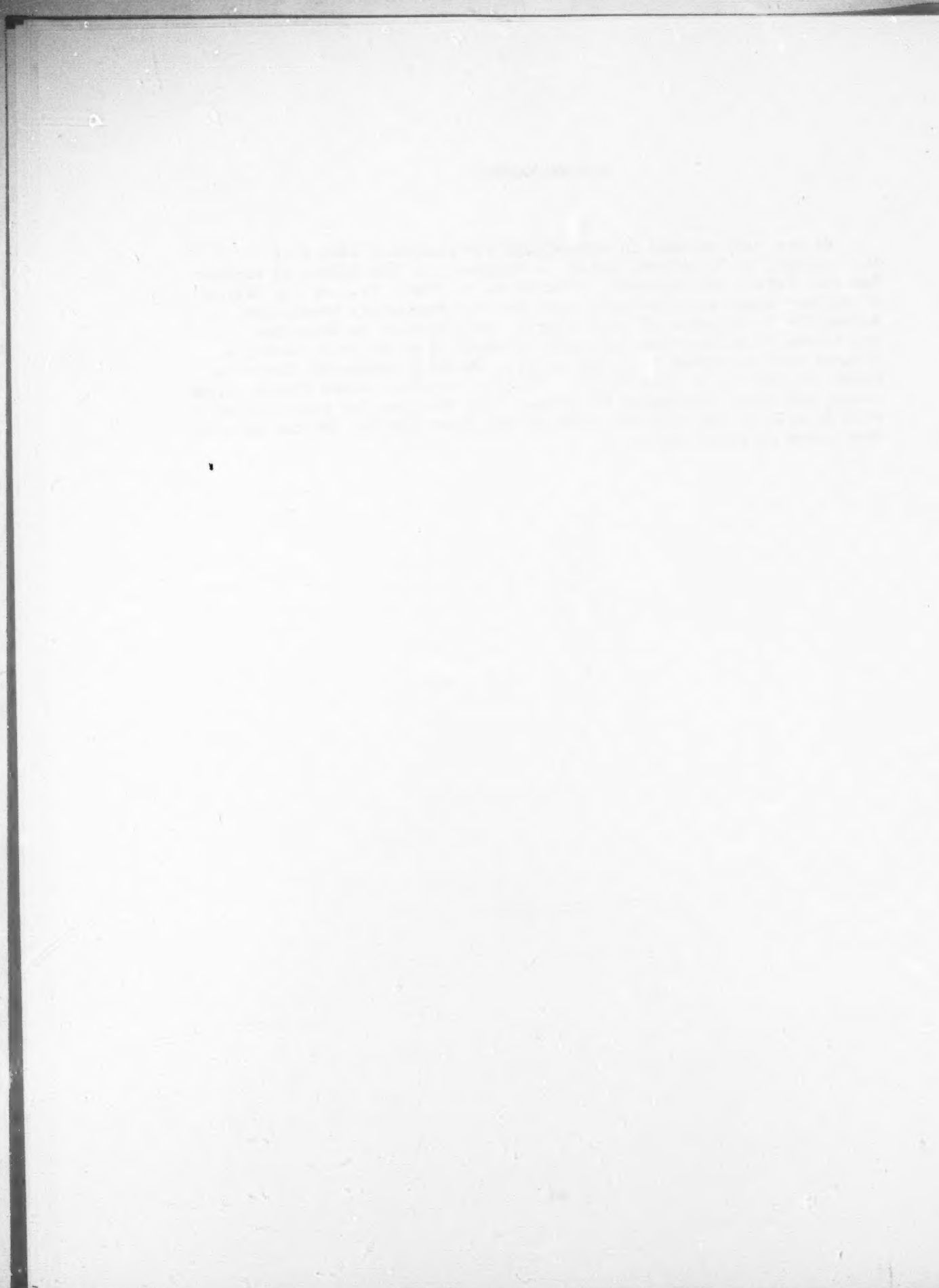
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POTENTIAL RADIOLOGICAL IMPACT OF TORNADOES ON THE SAFETY OF
NUCLEAR FUEL SERVICES' WEST VALLEY FUEL REPROCESSING PLANT

I. TORNADO EFFECTS ON HEAD-END CELL AIRFLOW

L. J. Holloway

R. W. Andrae

ABSTRACT

This report describes results of a parametric study of the impacts of a tornado-generated depressurization on airflow in the contaminated process cells within the presently inoperative Nuclear Fuel Services fuel reprocessing facility near West Valley, N.Y. The study involved the following tasks: (1) mathematical modeling of installed ventilation and abnormal exhaust pathways from the cells and prediction of tornado-induced airflows in these pathways; (2) mathematical modeling of individual cell flow characteristics and prediction of in-cell velocities induced by flows from step 1; and (3) evaluation of the results of steps 1 and 2 to determine whether any of the pathways investigated have the potential for releasing quantities of radioactively contaminated air from the main process cells. The study has concluded that in the event of a tornado strike, certain pathways from the cells have the potential to release radioactive materials to the atmosphere. Determination of the quantities of radioactive material released from the cells through pathways identified in step 3 is presented in volume 2 of this report.

1. INTRODUCTION

The primary objective of this study is the determination of potential radiological impacts of a tornado strike at the presently inoperative Nuclear Fuel Services' (NFS) fuel reprocessing plant located near West Valley, N.Y. Considerable quantities of radioactive materials remain in the head-end cells [60 to 600 kg in the process mechanical cell (PMC) and 50 to 500 kg in the general-purpose cell (GPC)] (see Part II of this report¹) as a result of previous reprocessing operations. There is concern about the ability of the cells and ventilation system to adequately provide containment of this material when subjected to tornado-induced forces. The present report involves analysis of the

factors that could lead to transport of radioactive material from the cells to the atmosphere during a tornado. In Part II of this report,¹ the determination of quantities of radioactive material that could be discharged from the cells under tornado accident conditions is described.

Nuclear Fuel Services, Inc., established the first commercial facility for processing spent nuclear fuels at West Valley, N.Y., on property of the Western New York Nuclear Services' Center (WNYNSC) in 1966. The plant was operated until 1972, during which time 640 metric tons of irradiated fuel was processed. The plant was originally shut down in 1972 because of plans to expand capacity; on September 22, 1976, NFS announced its decision to withdraw from the nuclear fuel reprocessing business. The history of the WNYNSC and the interactions of local residents and local, state, and federal agencies have been documented.²

The Nuclear Regulatory Commission (NRC) has requested an analysis of the effect of a tornado strike at the reprocessing plant.³ Gamma-ray dose rate measurements have enabled estimates of the quantities of radioactive materials in the PMC, the GPC, and the chemical process cell (CPC).

Because of the massive thickness of cell walls and floors, no significant structural damage to the head-end cells is expected during a tornado strike. The transient depressurization associated with the vortex motion of air within a tornado could function to draw radioactive materials from the head-end cells through insufficiently sealed or unfiltered pathways. Several pathways of this type were left in the cell walls when equipment was removed during plant shutdown. Backflow pathways could potentially be the most severe because no filtration would be provided. This study involves determination of the potential for release of radioactive materials through the identified pathways during a tornado (Part I) and estimation of the quantities of material that would be released (Part II).

The following tasks were involved in this study.

1. identification of all pathways through which air could flow from the cells (Part I);
2. prediction of tornado-induced airflows through these pathways (step 1) from the cells (Part I);
3. prediction of tornado-induced air velocities over surfaces within the cells where deposited radioactive material is likely (Part I);
4. estimation of quantities of radioactive materials and size distribution of these materials within the cells (Part II);

5. determination of quantities of radioactive materials that would be resuspended from the cell floor by higher than normal tornado-induced air velocities (from step 3) in the cells (Part II);
6. determination of quantities of radioactive materials that would be drawn from the cells to the atmosphere through unfiltered pathways by tornado-induced airflows (combination of steps 2 and 5) (Part II).

In an effort to learn how radioactive materials might be transferred through ventilation systems under tornado conditions, the U.S. Department of Energy sponsored a study by Los Alamos Scientific Laboratory of tornado-induced airflow in nuclear facilities.⁴ The LASL study led to the development of the TVENT⁵ computer code designed to predict one-dimensional tornado-induced flows and pressures in the ventilation system of a nuclear facility. The NRC has used TVENT to determine the potential for radioactive particulate release from the NFS facility. TVENT was used in step 2 of the present analysis to predict the dynamic characteristics of air movement within the NFS plant caused by a range of hypothetical transient conditions.

Under the same DOE sponsored study, another computer code, SOLA-ICE,⁶ was modified by LASL to utilize the TVENT output of airflows in the cell ventilation system. The output served as boundary conditions for calculating the detailed two-dimensional, tornado-induced air velocities within the cells over surfaces where deposited radioactive material is likely. Analysis of the NFS facility was performed using the SOLA-ICE code to predict air velocities in the cells (step 3 of this analysis).

The analysis was performed as a parametric study, using a range of tornadoes postulated to strike the NFS facility. Tornadoes with maximum wind speeds of 100, 200, and 300 mph were considered in this analysis. No attempt was made in this study to assess the likelihood of occurrence of any particular tornado.

One topic not analyzed in this study concerns the structural integrity of process building walls and doors under tornado-induced loadings. The analysis was performed assuming for one condition that exterior walls and doors would remain intact and for the other condition that they would be destroyed by the tornado.

The following section is a summary of the basic analysis involved in Part I, that is, the estimation of tornado-induced head-end cell airflows for each pathway. Conclusions concerning the pathways with greatest potential for release of materials are also presented.

2. SUMMARY

Analysis of the factors that could lead to transport of radioactive materials from the NFS head-end cells to the atmosphere during a tornado strike involved the development, implementation, and integration of a variety of analytical tools. Investigation of a number of distinct phenomena was required in areas including site meteorology, mechanical design of airflow systems, compressible and incompressible flow analysis, radiation shielding analysis, particle size analysis, aerosol science, atmospheric dispersion, and uptake and dose-rate modeling. An unusual aspect of this type of analysis, involving consideration of airflows from the facility, is that unless it can be determined at the start that no pathways for airflow from contaminated areas exist, all phenomena must be investigated in order to reach conclusions that can be substantiated. No single factor will determine whether a release potential exists. The analytical procedures developed for the entire study are described in Section 3.

In Section 4, the determination of potential airflow pathways from the cells and the modeling of these paths for computer analysis are described. Two visits to the site as well as examination of detailed facility drawings were required in order to identify all possible pathways. All potential pathways were investigated including those involving reverse flow. Preliminary analysis indicated that some pathways did not have significant release potential because of substantial airflow restrictions or filters, and those were eliminated from further consideration.

Several pathways were discovered which are unique to this facility because of its inoperative status. In the PMC and the GPC, a number of manipulators had been removed from the cell walls after plant shutdown and replaced by substantial plugs or covered with plywood or in a few cases with cardboard. Forces accompanying a tornado either from high winds or from depressurization would be sufficient to pull covers from some of the ports and possibly draw contaminated air from the cells.

Another unusual pathway involved an open 8-in.-diam duct in the GPC wall through which a hose to provide carbon dioxide for fire protection passed into the cell. The normal cell fire protection system had been shut down in order to reduce personnel and equipment usage requirements for the inoperative facility.

Modeling of these pathways for computer analysis with the TVENT code required slight modifications in established procedures for utilizing the code in order to model loss of covers over ports in the cell walls during a tornado-induced pressure transient. These procedures are described in Section 3.

In Section 5, results of the TVENT analysis are presented in the form of airflow rates and total volumes of air discharged through each pathway from the cells. The predictions of airflow for 100-, 200-, and 300-mph tornadoes were examined to determine whether air from the cells would flow to the atmosphere through unfiltered pathways. This airflow would be opposite to the normal direction of flow, which is from corridors and rooms adjoining the cells into and through the cells to a filtration system, exhaust blowers, and stack discharge.

Conclusions from this analysis are that for certain of the pathways and tornado wind speeds examined, the tornado depressurization would not be sufficient to overcome the induced draft from exhaust blowers, which acts to pull air into and through the cells; for these cases, no air could be drawn from the cells to the atmosphere through unfiltered pathways, and no potential for release of radioactive materials exists. For a few other cases examined, analysis indicated that tornado-induced forces have the potential to draw unfiltered air from the cells. The pathways with the greatest potential for release of unfiltered air were identified as seven unsealed manipulator ports in the walls of the PMC. The analysis also indicated that several other pathways had minor release potential.

After identification of pathways and tornado conditions with release potential (by TVENT analysis), it was necessary to determine whether air velocities generated within the cells for these cases would be sufficient to reentrain radioactive particles from contaminated surfaces and transport this material from the cells. The SOLA-ICE computer code was used for this analysis by LASL, and the results are presented in Section 6. SOLA-ICE-predicted velocities over the cell floors were used as described in Part II to predict quantities of material released from the cells.

3. ANALYTICAL PROCEDURES

A primary purpose of this report is the documentation of analytical techniques developed for evaluating tornado effects on the NFS facility. Techniques for analyzing the effects of natural phenomena on nuclear fuel cycle facilities are still evolving. In this section an attempt is made to document the step-by-step procedures developed for this task in order that the techniques may be utilized in future evaluations.

3.1 General Procedures

A structural evaluation to determine loss of facility integrity and damage under extreme conditions generated by natural phenomena is normally the first step in an analysis of this type.^{7,8,9} For the NFS facility, the assumption was made at the outset that the 5- to 6-ft-thick reinforced concrete head-end cells containing radioactive materials would not be damaged by tornado-induced forces. This is a reasonable assumption for reinforced concrete enclosures of this size. It was assumed that the cells would remain intact, with only small penetrations to the cells unprotected from tornado forces (i.e., ports for manipulators, fire protection ports, etc.).

It was also assumed that the exterior building walls constructed of concrete block and sheet metal would sustain damage under tornado conditions such that the head-end cells within would be exposed to tornado-induced forces. The assumed level of damage to the exterior walls and doors ranged from loss of portions of the sheet metal or exterior doors under lesser tornadoes to complete collapse of the exterior building when subjected to the highest tornado considered.

In the ongoing NRC evaluations of tornado effects on plutonium facilities,^{7,8} analysis indicates that the primary containment structures (glove boxes) would not remain intact, and the radioactive materials within would be dispersed to the surroundings by tornadic winds. In the case of the NFS facility, primary containment is provided by the massive reinforced concrete cells, which would remain intact during a tornado. The only mechanism which could induce a release of radioactive materials under tornado conditions is the transient depressurization associated with a tornado. The depressurization created by the vortex motion of air within a tornado could induce higher than normal airflows, flow reversals, and pressure differences in the cells and draw air containing radioactive particles out of the cells through existing unfiltered penetrations in the cell walls.

The following is a summary of the steps involved in the process of determining the potential for discharge and the quantities of radioactive materials which could be discharged from the NFS facility under tornado accident conditions.

1. Examine the facility to determine pathways through which unfiltered air containing radioactive materials could be drawn from the main process cells to the surroundings by a depressurization associated with a tornado.
2. Model the cell ventilation pathways and other identified airflow pathways from step 1 for computer analysis with the TVENT code.
3. Characterize a range of tornadoes for the geographic location of the facility by the following parameters: maximum wind speed, rotational and translational speeds, radius of maximum winds, total pressure drop, and rate of pressure drop.
4. Utilizing the TVENT code, predict transient flows and pressures in cells and airflow pathways induced by the transient depressurization accompanying a tornado.
5. Examine tornado-induced airflows in the system (step 4) to determine if air potentially containing radioactive materials could flow from the head-end cells through unfiltered pathways to the atmosphere. The volumes of air flowing through each pathway over a period of time and the flow velocities in each pathway are output from TVENT (step 4).
6. Model the individual cells from which contaminated air could flow (step 5) and analyze the model with the SOLA-ICE computer code. SOLA-ICE utilizes airflow velocities through each path from the cell (TVENT output) as input for predicting two-dimensional transient velocities within the cell. The velocities near surfaces where deposited radioactive material is likely are the quantities of interest.
7. Estimate quantities of radioactive materials deposited on surfaces of head-end cells, utilizing dose rate measurements from the cells, an estimate of the typical or average fuel processed at NFS, the gamma-ray spectrum of the reference fuel calculated by the ORIGEN¹⁰ code, and dose conversion factors determined from the SDC¹¹ gamma-ray shielding code (Part II of this report).
8. Estimate the particle size distribution of radioactive materials on surfaces of cells, using particle size information from processing of similar fuels (Part II of this report).

9. Determine terminal settling and threshold friction speeds (air speeds required to lift and carry, reentrain, particles from a surface) for the size distribution of radioactive materials in the cells (Part II of this report).
10. Using the tornado-induced near floor air speeds in the cells predicted with the SOLA-ICE code (step 6), the particle size distribution of materials in the cell (step 8), and the terminal settling and threshold friction speeds (step 9), estimate the quantities of radioactive material that would become airborne by tornado-induced airflows (Part II of this report).
11. Using volumes of air discharged from the cells as predicted by the TVENT analysis (step 4), determine whether radioactive particles reentrained from the cell floors would be discharged to the atmosphere. The amount of material discharged is the source term (Part II of this report).

The final step in this type of analysis would be determination of the effects of the release predicted in step 11 on operating personnel, the public, and the surrounding environment, using appropriate atmospheric dispersion, uptake, and dosage models. This evaluation was not included in the scope of the present study and will not be addressed in this report.

Part I of this report addresses in detail the analysis and results of steps 1 to 6 involving the effects of a tornado on airflow in the head-end cells. Part II of the report¹ addresses steps 7 to 11 of the analysis, including predictions of the quantities of material released during a tornado strike.

In the following section, details involved in utilizing the analytical methods described in steps 1 to 6 are presented. Detailed techniques utilized in steps 7 to 11 are presented in Part II of this report.¹

3.2 Detailed Analytical Techniques

The computer code selected by the NRC staff for use in this evaluation is TVENT,⁵ developed at IASL. This code was developed by R. W. Andrae, K. H. Duerre, and W. S. Gregory of IASL as a tool for predicting responses of ventilation systems to tornado-induced pressure transients. A description of TVENT along with its capabilities and limitations is included in Appendix A.

In modeling a ventilation system for analysis with TVENT, step 2, it is necessary to determine the flow characteristics of the system under normal operating conditions. Operating pressures and flows and the location of ventilation components such as valves, filters, and blowers are required for input to TVENT and were obtained for the NFS facility from drawings of the head-end ventilation system and from instrumentation located at the plant. Flow characteristics of the system under normal operating conditions are presented in Sect. 4.2.

In modeling the ventilation system and other exhaust pathways at the NFS facility, several alterations to specific flow characteristics of the normal operating system were required in order to simulate behavior of certain portions of the system during a tornado. Since TVENT performs a steady state analysis of a modeled system to establish system resistances before the transient analysis, it was necessary to develop several techniques for modeling the transient behavior of parts of the system while not altering resistances in the remainder of the system.

TVENT assumes a fixed geometry in the analysis of a ventilation system; thus, techniques were required for modeling partial and complete failure of the exterior walls of the NFS building. The simulation of partial wall failure was accomplished by including a small resistance to airflow for the exterior walls in the system model.

Modeling complete exterior wall failure was accomplished by utilizing the "restart" option of TVENT. A steady state analysis of the system model with normal operating flow characteristics is performed assuming the exterior walls are intact; that is, resistances are included in the model for the exterior walls. Using the system resistances established in the steady state analysis, a transient analysis is performed but with resistances provided by the exterior walls deleted. Thus the effect of loss of exterior walls on the ventilation system can be determined without altering resistances to airflow within the system. More specific details involved in this technique are discussed in Appendix B.

A similar technique was used to model the removal of plywood and cardboard covers from exhaust pathways in the cells when pressure gradients across these covers reached a certain point. Calculations (see Appendix B) indicate that a pressure differential of 0.4 in. H₂O (0.014 psi, cell pressure positive relative to surroundings) would be sufficient to dislodge plywood covers over manipulator ports in the PMC and cardboard covers over ports in the GPC. This pressure differential was predicted by TVENT to occur for the 100-, 200- and 300-mph tornadoes at 2.7, 0.9, and 0.6, respectively, after the start of the tornado-induced transient. At these times, each case was restarted with altered resistances to reflect loss of the covers, and the transient analysis was continued.

Boundary points are present in the facility such as exterior doors or openings to the atmosphere through which air would flow out of the building if a positive pressure differential were applied at these points. Normally, pressure differentials across doors and vents in exterior walls of the building are negative with respect to the atmosphere (interior corridors of the building are held at -0.05 to -0.1 in. H_2O with respect to atmospheric pressure). A low-pressure area such as that occurring within a tornado could create a positive pressure differential across vents and doors, causing air to flow out of the building through unfiltered pathways in a direction opposite to normal flow.

When using TVENT, it is necessary to define a time-dependent pressure function representing depressurization effects which would occur as a tornado crosses a boundary point (step 3). This pressure function is used as a forcing function by TVENT in predicting pressure and flow transient responses within the modeled system as a result of a low-pressure function at the boundary points. An analytical tornado model developed by Fujita,¹² DBT-78, was selected by the NRC staff as appropriate for determining pressure functions for 100-, 200-, and 300-mph tornadoes. Parameters necessary for determining pressure functions based on tornado model DBT-78 are given in Table 3.1.

Table 3.1. Tornado parameters based on DBT-78 tornado model^a

Maximum tangential velocity (mph)	Radius (m)	Total pressure drop (psi)	Pressure drop rate (psi/s)
100	56	0.18 (4.9 in. H_2O)	0.03 (0.9 in. H_2O/s)
200	108	0.63 (17.6 in. H_2O)	0.12 (3.4 in. H_2O/s)
300	157	1.3 (36.3 in. H_2O)	0.26 (7.2 in. H_2O/s)

^aSee Ref. 12.

Pressure transients derived from the parameters given in Table 3.1 are shown in Fig. 3.1 for the 100-, 200-, and 300-mph tornadoes. An assumption made in deriving these pressure functions was that the maximum total pressure drop within the tornado would last for 4 s as the

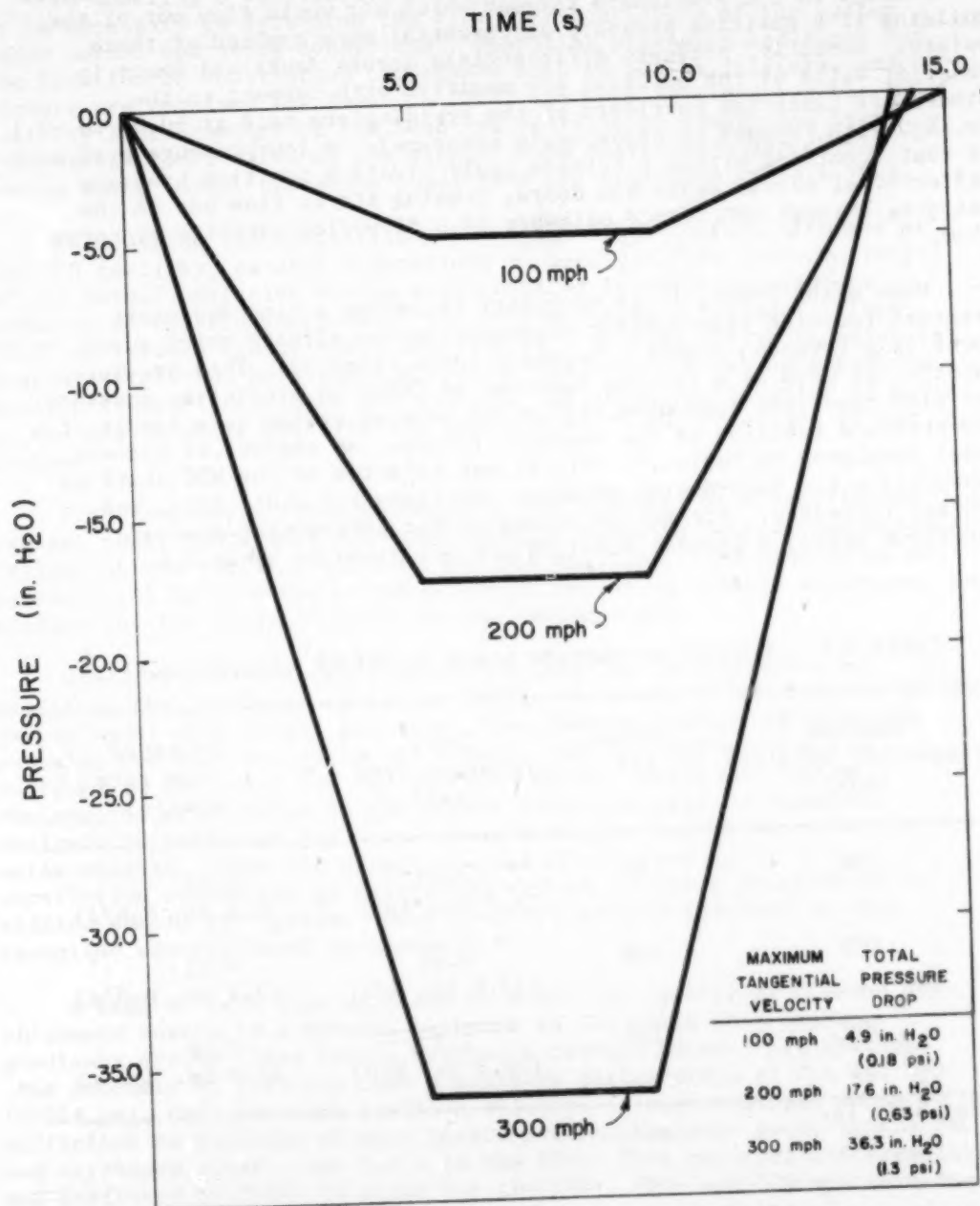


Fig. 3.1. Tornado pressure functions for input to TVENT. Based on tornado model DBT-78 (ref. 10).

tornado crossed the facility. Calculations supporting this assumption based on the translational velocity of the tornado, the tornado diameter, and the building length are described in Appendix B.

A primary concern in analyzing a ventilation system for tornado effects is the effect of internally generated pressure transients and pressure differentials on HEPA filters within the system. High-pressure differentials or tornado-induced pressure shocks could cause failure of the filters, resulting in a release of unfiltered air through the normal ventilation exhaust pathway.

Tornado-induced pressure differentials across HEPA filters in the NFS ventilation system as predicted by TVENT were not sufficient to cause filter failure. The highest pressure differential predicted across a HEPA filter for all the cases and conditions analyzed was 17.5 in. H₂O, which would occur across a filter in the air supply path for the CPC. An investigation conducted by LASL¹³ of HEPA filter failure during overpressurization has indicated that the average break pressure for the weakest filter tested was 1.32 psi (36.5 in. H₂O) with a standard deviation of 0.22 psi. With two standard deviations, the break pressure is still 0.88 psi (24.4 in. H₂O), which is above the highest pressure differential occurring in the NFS analysis. Thus it was determined that all HEPA filters within the NFS facility would remain intact under tornado accident conditions, provided the structure housing the filter remained intact and any releases of air through these paths (in the normal or reverse directions) would be filtered. Emphasis in analyzing release pathways from the head-end cells was thus placed on unfiltered pathways.

In analyzing the NFS facility for tornado effects (step 4), two different modes of tornado impact were postulated, and both were applied to each case being considered. In the first mode, the tornado would simultaneously impact all facility portals (boundary points) through which air is both supplied to and exhausted from the ventilation system. In the second mode, the tornado would strike the portion of the building in which boundary points for air supply to the ventilation system are located while not striking the point of ventilation exhaust located approximately 100 ft away.

In the main process building, air is supplied to the head-end ventilation system by stairwells located at the building perimeter. Air intakes for the building are supplied by outside air vents in the stairwells. Since the stairwells supplying air are interconnected, ventilation air for the CPC would originate from the same source as that for ventilation air for the PMC or GPC; therefore, the low-pressure area within a tornado would affect all three supply points equally and simultaneously.

Under normal operating conditions, ventilation air from the process cells is exhausted through an underground duct to a filter house containing a bank of roughing filters and HEPA filters. Two 7000 cfm

fans then force the filtered air to an exhaust stack located on the building roof, where it is released to the atmosphere. Since the filter house is located approximately 100 ft from the stairwells which supply air to the ventilation system, it is possible, because of the random behavior and movement of tornadoes, for the ventilation supply points to be affected by the tornado, while the exhaust point is not.

Analysis of all postulated release pathways for the two modes of tornado impact indicated that the second mode predicted higher volumes of unfiltered air released from the cells than did the first mode (step 5). Higher volumes would be released during the second mode, because in the first mode a lower back pressure from the tornado is applied at the normal exhaust point and eventually lowers the cell pressures, creating less of a pressure differential to force air out of the unfiltered exhaust pathways. To simplify presentation of results, only the second impact mode will be considered, since it presents the "worst case" for this analysis.

The procedures outlined in this section may be useful in evaluating tornado effects on other nuclear facilities and should be modified to suit the particular facility being analyzed. More detailed modeling techniques and analysis results are described in the remainder of this report and in Part II.¹

4. HEAD-END CELL AIRFLOW ANALYSIS

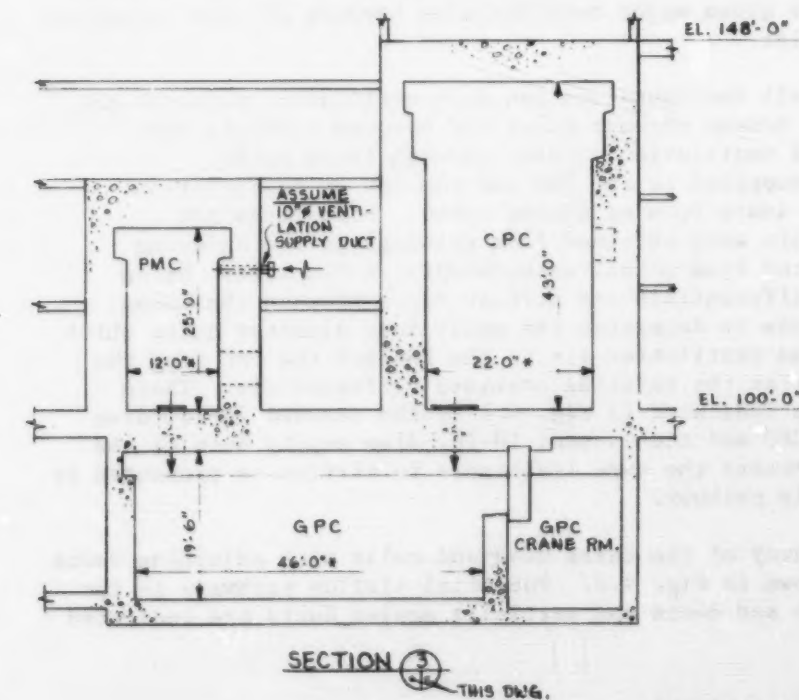
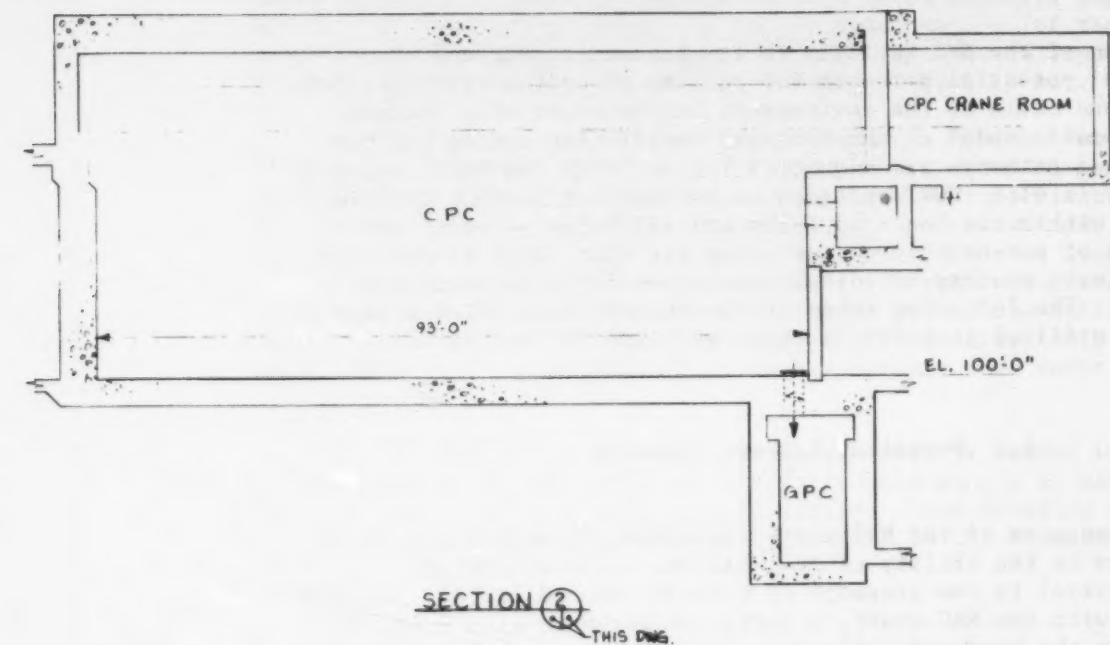
Examination of the NFS facility in its present shutdown status revealed several potential pathways for release of radioactive material from the head-end cells to the environment in the event of a tornado strike. A schematic model of the head-end ventilation system and the potential release pathways was developed for use with the TVENT computer program. Analysis with TVENT provided an estimate of maximum airflows to be expected within the head-end cells and adjoining pathways and maximum volumes of potentially contaminated air that could be released from facility (main process building) boundaries during a postulated tornado strike. The following subsections describe identified pathways and techniques utilized in modeling these pathways for analysis.

4.1 Potential Release Pathways

A primary concern of the NRC staff investigating safety aspects of the NFS facility is the ability of the head-end cells to contain radioactive material in the presence of tornado-induced forces. Working in conjunction with the NRC staff, a number of pathways with potential for release from the head-end cells were identified. Pathways from the GPC and the PMC were given major consideration because of high radiation levels in these cells.

The head-end cell configuration and cell ventilation pathways are shown in Fig. 4.1. Arrows through ducts and hatches indicate the directions of normal ventilation airflow through these paths. Ventilation air is supplied to the PMC and the CPC by infiltration through gaps around doors from adjoining rooms. Flow rates for ventilation supply air were obtained from drawings of the existing ventilation system and from actual measurements at the site. Using measured pressure differentials and airflow rates between the rooms, calculations were made to determine the equivalent diameter ducts which would supply required ventilation air to the PMC and the CPC from the surrounding corridor at the existing pressure differentials. These equivalent ducts are indicated in Fig. 4.1 by the assumed 36-in.-diam supply duct to the CPC and the assumed 10-in.-diam supply duct to the PMC. The ducts represent the same resistance to airflow as presented by the actual air supply pathway.

A dimetric cutaway of the three head-end cells with adjoining rooms and corridors is shown in Fig. 4.2. Potential airflow pathways in the form of open hatches and ducts and partially sealed ducts are indicated in this drawing.



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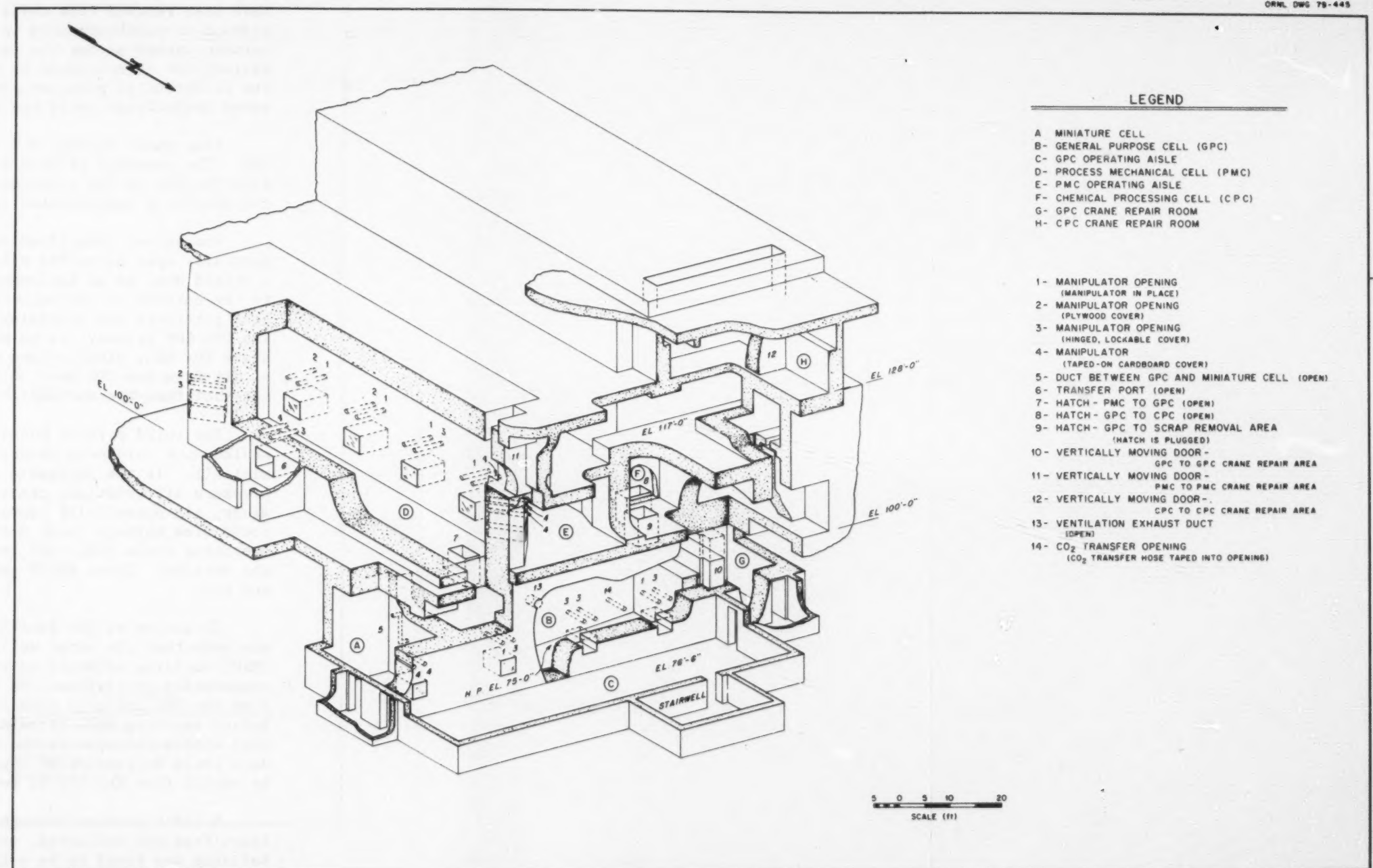


Fig. 4.2. Dimetric cutaway of NFS head-end cells.

The most obvious and, as later established, most critical pathway is through seven manipulator ports in the PMC cell walls. Manipulators have been removed from these ports and the openings covered with either plywood or cardboard held in place by duct tape to the cell walls. If a tornado passed across the facility in the vicinity of the PMC, these manipulator covers would be removed by either tornado-induced winds or the differential pressure produced by the tornado. Locations of the seven manipulator ports are indicated in Fig. 4.2 by labels 2 or 4.

Also shown in Fig. 4.2 is an open hatch connecting the PMC and the GPC. The presence of this hatch is significant because a release of air from the PMC to the atmosphere has the potential for containing radioactively contaminated air from the GPC.

The second identified release pathway is from the CPC through a partially open butterfly valve (operating position open) and gap around a shield door to an equipment decontamination room (EDR) with accesses to the outside of the building. A block diagram indicating cell configurations and adjoining rooms and connections is shown in Fig. 4.3. The CPC-EDR pathway can be seen on this diagram. The CPC is located above the GPC, with an open hatchway joining the two so that any release of air from the CPC has the potential for containing radioactive material from the much more highly contaminated GPC.

The third pathway considered involves three ducts temporarily sealed with cardboard covers in the walls of the GPC and the adjoining minicell. If the cardboard covers could be removed as a result of pressure differentials created by tornadic winds or by the force of the winds, air potentially contaminated with radioactive particulate matter could flow through these ducts to the surrounding general-purpose operating aisle (GOA) and from this aisle to an adjoining stairway to the outside. These ducts and room configurations are shown in Figs. 4.2 and 4.3.

To arrive at the fourth possible pathway, a conservative assumption was made that the outer walls or roof of the master-slave manipulator (MSM) building adjacent to the main facility building poses no restriction to airflow. As indicated in Fig. 4.3, the main exhaust duct from the GPC connects with the main exhaust duct from the MSM building before reaching HEPA filters and exhaust blowers. It is conceivable that with a collapse of the MSM building walls or roof, this exhaust duct could be penetrated thus providing a path for contaminated air to be vented from the GPC to the atmosphere.

A fifth pathway through several rooms adjoining the PMC was identified and evaluated, and its contribution to a release from the building was found to be negligible. This pathway is from the PMC through a labyrinth joint between a sliding shield door and fixed walls to the mechanical-crane room. From this room, air could flow through an open hatch to the manipulator repair room and through an air lock with a

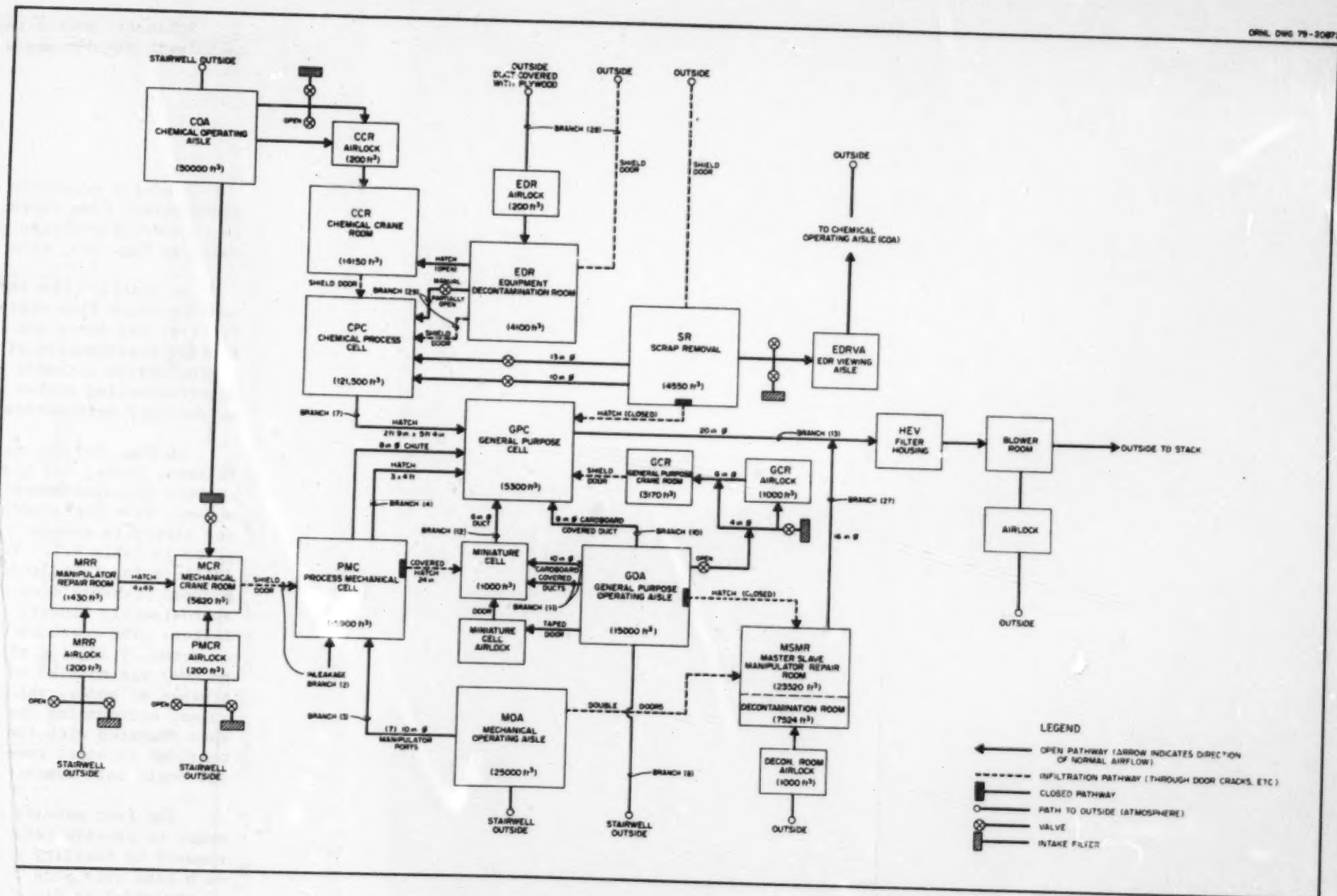


Fig. 4.3. NFS cell configuration, block diagram.

plastic-covered door to the outside. This configuration is also shown in Fig. 4.3.

Schematic models representing the four major pathways and modeling techniques are discussed in the following section.

4.2 Modeling Techniques

A single schematic model was developed to represent the mathematical flow characteristics of the head-end ventilation system and four potential release pathways described in Sect. 4.1. This model is shown in Fig. 4.4, with flows indicated for normal operating conditions.

In modeling the ventilation system, a lumped parameter approach was used in which flow characteristics of components such as dampers, filters, and ducts are lumped within system elements or branches, and spatial distribution of variables is neglected. The connection points of the system elements or branches are denoted as nodes, and the interconnecting system of nodes and branches forms a network which can be analyzed mathematically to determine system performance.

In Fig. 4.4 the major components of the ventilation system, valves, filters, ducts, and blowers, are located on branches as denoted by the numbers in parentheses. These components are connected by numbered nodes. Flow characteristics of components within the cell ventilation and alternate exhaust pathways under normal operating conditions are given in Table 4.1. The filters in branches 2 and 6 represent infiltration to adjacent cells from surrounding rooms. The relationship between pressure drop and airflow rate through an infiltration path is approximately linear, as is the pressure drop flow relation across a filter. The corridor surrounding the PMC, represented by a room at node 2, actually adjoins other rooms in addition to the PMC; however, the pathway was modeled to utilize the TVENT capability of allowing fluid storage at nodes, which would represent damping effects of a large volume surrounding the PMC on flow out of the cell to the atmosphere. When compared with the effect on flow from the PMC, connection of the corridor to other rooms would have an insignificant effect on results and would only complicate the modeling unnecessarily.

The four potential pathways were actually analyzed separately in order to provide information in the event that one or more pathways were removed by facility modifications. Alterations as described below for each case were made in pressure and flow or resistance characteristics of the model in Fig. 4.4 according to which pathway was being considered. In this way, the necessity for developing four separate models was avoided by simple modifications to a single model. The four cases analyzed are described below.

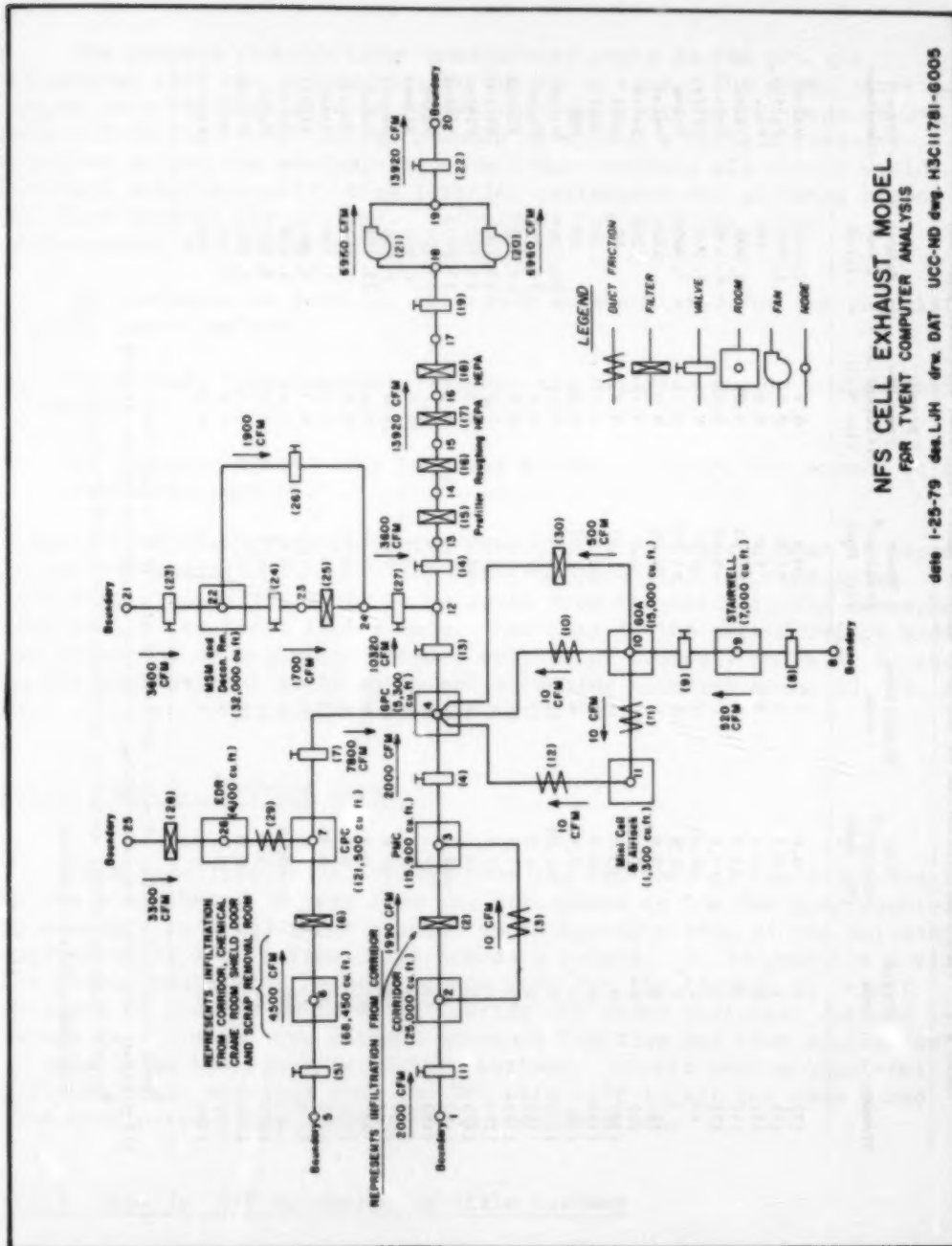


Fig. 4.4. Schematic model of NFS cell exhaust system for TVENT computer analysis.

Table 4.1. Flow characteristics of NES cell exhaust model for TVENT computer analysis

Branch	Upstream node	Node pressure ^a (in. H ₂ O)	Downstream node	Node pressure ^a (in. H ₂ O)	Branch pressure differential (in. H ₂ O)	Branch flow ^b (cfm)	Branch component
(1)	1	0.0	2	-0.1	0.1	2,000	Valve ^c
(2)	2	-0.1	3	-1.0	0.9	1,990	Filter
(3)	2	-0.1	3	-1.0	0.9	10	Duct
(4)	3	-1.0	4	-1.01	0.01	2,000	Valve
(5)	5	0.0	6	-0.05	0.05	4,500	Valve
(6)	6	-0.05	7	-0.9	0.85	4,500	Filter
(7)	7	-0.9	4	-1.01	0.11	7,800	Valve
(8)	8	0.0	9	-0.05	0.05	520	Valve
(9)	9	-0.05	10	-0.2	0.15	520	Valve
(10)	10	-0.2	4	-1.01	0.81	10	Duct
(11)	10	-0.2	11	-0.95	0.75	10	Duct
(12)	11	-0.95	4	-1.01	0.06	10	Duct
(13)	4	-1.01	12	-6.5	5.49	10,320	Valve
(14)	12	-6.5	13	-7.2	0.7	13,920	Valve
(15)	13	-7.2	14	-7.7	0.5	13,920	Filter
(16)	14	-7.7	15	-9.7	2.0	13,920	Filter
(17)	15	-9.7	16	-18.2	8.5	13,920	Filter
(18)	16	-18.2	17	-19.5	1.3	13,920	Filter
(19)	17	-19.5	18	-19.6	0.1	13,920	Valve
(20)	18	-19.6	19	0.4	20.0	6,960	Blower
(21)	18	-19.6	19	0.4	20.0	6,960	Blower
(22)	19	0.4	20	0.0	0.4	13,920	Valve
(23)	21	0.0	22	-0.15	0.15	3,600	Valve
(24)	22	-0.15	23	-5.5	5.35	1,700	Valve
(25)	23	-5.5	24	-5.8	0.3	1,700	Filter
(26)	22	-0.15	24	-5.8	5.65	1,900	Valve
(27)	24	-5.8	12	-6.5	0.7	3,600	Valve
(28)	25	0.0	26	-0.3	0.3	3,300	Filter
(29)	26	-0.3	7	-0.9	0.6	3,300	Duct
(30)	10	-0.2	4	-1.01	0.81	500	Filter

^aNode pressure in inches of water absolute (1 atm = 0.0 in. of water).

All pressures are under normal operating conditions without the tornado present.

^bBranch flows for normal operating conditions without tornado present.^cRepresents valve or damper.

4.2.1 Case 1. PMC manipulator port pathway

The pathway through seven manipulator ports in the process mechanical cell was considered for the first case. The seven ports were lumped into one duct with an equivalent resistance as represented by branch 3 in Fig. 4.4. It was assumed that when a certain pressure gradient across the manipulator covers was reached, all covers would dislodge simultaneously, thus lowering resistance and allowing higher air flow through the pathway. Techniques for modeling cover dislodgement are discussed in Appendix B.

As discussed in Sect. 3, all cases were analyzed for two postulated tornado impact modes:

1. the tornado simultaneously impacts all building supply and exhaust points,
2. the tornado impacts only boundary points providing air supply to the ventilation system.

Results of the analysis indicated that during the second mode of impact, larger volumes of unfiltered air with the potential for containing radioactive materials would be released from the cells to the atmosphere than during the first impact mode. For case 1, the second impact mode was simulated by applying tornadic effects at boundary nodes 1, 5, and 8 in the mathematical model while not affecting boundary nodes 20, 21, and 25.

4.2.2 Case 2. CPC-FDR pathway

This case involved a pathway from the CPC through the adjoining FDR to the atmosphere. Access from the atmosphere to the FDR (represented by boundary node 25) is at a point on an opposite side of the building approximately 100 ft from other boundary points. It is possible during the second postulated tornado impact mode for the tornado to impact accesses to the FDR while not affecting the other portals. For the second impact mode, the tornado pressure function was thus applied only at node 25 in the analysis of this pathway. Covers over manipulator ports and over openings into the GPC were left intact for case 2 and thus eliminated these pathways from consideration.

4.2.3 Case 3. GPC to operating aisle pathway

Pathways through a cardboard-covered fire protection duct in the GPC wall and through two cardboard-covered manipulator ports in the adjoining minicell walls were analyzed in case 3, with manipulator ports

in the PMC walls sealed. For the second tornado impact mode, the tornado pressure function was applied to nodes 1, 5, and 8 as in case 1. As discussed in Sect. 3.2, the physical locations of boundary points 1, 5, and 8 in the building are in the main building stairwell, and all three points would be simultaneously and equally affected by a tornado. Techniques for simulating loss of cardboard covers during the tornado transient are similar to that used in case 1 for the PMC manipulator covers and are described in Appendix B.

4.2.4 Case 4. GPC-MSM building pathway

In the final case the pathway considered is from the GPC through its main exhaust duct to the MSM building exhaust duct, which has been penetrated and exposed to the atmosphere by collapse of the MSM building walls. The MSM building and exhaust blower and filter house are closely located and could be exclusively affected by the tornado. The technique for simulating loss of MSM building walls is discussed in detail in Appendix B. In summary, resistances to airflow provided by branches 23, 24, 25, and 26 in the model are deleted, and the tornado is applied at node 24. At the same instant, the tornado is applied to node 20, representing the boundary from the exhaust blower and filter housing. Covers over manipulator ports in PMC and GPC walls remain intact for this case.

The following section describes in detail results of analysis of the four potential release pathways described above.

5. HEAD-END CELL AIRFLOW UNDER TORNADO CONDITIONS

In interpreting results of the analysis of head-end cell airflow, the TVENT output of airflows and integrated volumes of air passing through each pathway was examined to determine whether air would flow from the cells to the atmosphere through unfiltered pathways. If a case were found to have unfiltered airflow to the atmosphere, volumes of air released were computed. For most of the postulated pathways, because radioactive material is deposited on the cell floors and not dispersed within the cell volume, a substantial quantity of air must be discharged from the cells before any contaminated air is released. A discussion of the basis for the required discharge volumes is given in Part II.

5.1 Air Discharge Volumes for Cases Analyzed

The pathway with highest potential for release of radioactive materials was found to involve the PMC manipulator sleeve ports considered in case 1. Volumes of air released through this pathway were the highest for any of the pathways considered, and the air released could contain radioactive materials from both the PMC and the GPC.

Some unfiltered volumes of air were predicted to be released to the atmosphere through all pathways investigated, but a release of air would not adversely affect the environment unless it contained radioactive materials. Part II describes the methods used to determine whether tornado-induced airflows within the cells could reentrain and release radioactive materials to the atmosphere.

As discussed in Part II, the air discharged from the contaminated process cells will always contain small quantities of radon from the decay chains of uranium and plutonium isotopes still in the head-end cells; however, the discharged air may not contain any particulate matter. In determining whether further analysis would be required for cases in which air is discharged from the cells, a volumetric shape for the air space within the cells prior to its discharge was assumed. If this air space intersected surfaces on which particulate matter is contained, then some calculable amounts of particulate radioactivity could be included in the release. If a predicted volume of released air produced a geometry which did not intersect contaminated surfaces, then this case was eliminated from further consideration because no radioactive particulate would be included in the release.

For cases involving a release from the PMC, the volumetric shape of air discharged through the manipulator ports is assumed to be quarter-spherical or a truncated cone centered at ports in the northwest corner of the cell (see Sect. 4.2.1, ref. 1). In order for this volume

to intersect the floor where contaminated material is deposited, the volume must be at least 1050 ft³. Cases involving discharges less than this amount are deleted from further consideration.

For cases involving discharges of air from the GPC through a port to the operating aisle, a hemispherical volume of 2100 ft³ is required before radioactive particulate can be released. This covers all of case 3. For cases 4 and 5, in which air is discharged from the GPC through the ventilation exhaust located near the ceiling of the cell, and for case 2, in which air passes through the GPC hatch in the ceiling to the CPC, a volume of 7700 ft³ is required before radioactive material is released. A further discussion of the basis for these estimates is presented in Part II.

Table 5.1 presents a summary of pathways through which a discharge of air from radioactively contaminated areas (head-end cells) was predicted during a postulated tornado strike. These predictions were made by analyzing the four cases described previously plus an additional case described below for effects of 100-, 200-, and 300-mph tornadoes, utilizing TVENT. For case 4A, analysis indicated that no releases from any of the contaminated cells could occur through this pathway.

A summary of estimated volumes of air discharged from the head-end cells during the three postulated tornado accident conditions is presented in Table 5.2. The branch designation above each column indicates through which branch in the NFS schematic model (Fig. 4.4) the estimated discharge occurs.

Air discharged from the PMC, GPC, and CPC has the potential to contain radioactive materials from these cells. The air released from these cells would not necessarily reach the outside but would be mixed with uncontaminated air in surrounding corridors before release to the ambient; therefore, the total discharge to the ambient from the release pathway (column 6) is a combination of uncontaminated and potentially contaminated air.

For case 1, the PMC manipulator sleeve pathway, substantial volumes of unfiltered air are predicted to be released from both the PMC and the GPC for 200- and 300-mph tornadoes for the conditions of both exterior walls intact and removed. Predicted volumes released for cases 1A1 and 1A2 were less than the required 1050 ft³, and these cases were deleted from further consideration. Unfiltered discharges of air through this pathway are caused by reversal of airflow in the PMC-GPC ventilation supply path and removal of plywood covers over the PMC manipulator ports due to the presence of a low pressure area within the tornado at the supply end of the ventilation system. Further analysis is required for cases 1B1, 1C1, 1B2, and 1C2 to determine the amount of radioactive material contained in air released through this pathway.

Table 5.1. Summary of pathways with discharges of air from radioactively contaminated areas (head-end cells) during postulated tornado strike^a

Pathway of release analyzed	Case	Tornado wind speed (mph)	Cell(s) from which potentially contaminated air is released
1 PMC manipulator sleeves to operating aisle ^b	1A1 Outer	100	PMC, GPC
	1B1 Walls	200	PMC, GPC
	1C1 Intact	300	PMC, GPC
	1A2 Outer	100	PMC, GPC
	1B2 Walls	200	PMC, GPC
	1C2 Removed	300	PMC, GPC
2 CPC EDR	2A	100	CPC
	2B	200	CPC
	2C	300	GPC, CPC
3 GPC to GPC operating aisle ^b	3A1 Outer	100	GPC
	3B1 Walls	200	GPC
	3C1 Intact	300	GPC
	3A2 Outer	100	GPC
	3B2 Walls	200	GPC
	3C2 Removed	300	GPC
4 MSM building	4A	100	none
	4B	200	GPC
	4C	300	GPC
5 Blowers inoperative	5A	100	GPC
	5B	200	GPC
	5C	300	GPC

^aAs determined from TVENT computer analysis of potential release pathways.

^bA release to the operating aisles was considered to be a release to the atmosphere because of the uncertainties regarding structural integrity of the exterior building walls and doors.

Table 5.2. Air volumes discharged from cells during postulated tornado strike

Case	Maximum tornado wind speed (mph)	Estimated by TVENT computer code				Total Discharge ^b to ambient from pathway (ft ³)
		Volume ^a released from PMC (ft ³)	Volume ^a released from GPC (ft ³)	Volume ^a released from CPC (ft ³)		
1A1 Outer	100	Branch 3 362	Branch 4 275	Branch 1 0	570	
1B1 walls	200	1273	1142	0	2300	
1C1 intact	300	1983	1922	0	3953	
1A2 Outer	100	484	439	0	Branches 2, 3 568	
1B2 walls	200	1947	2222	0	2792	
1C2 removed	300	3057	3912	0	5098	
2A	100	0	Branch 7 0	Branch 29 896	Branch 28 919	
2B	200	0	0	2522	2584	
2C	300	0	45	3934	3976	
3A1 Outer	100	0	Branches 10, 11 0.4	0	Branch 8 149	
3B1 walls	200	0	11.6	0	570	
3C1 intact	300	0	4.0	0	1001	
3A2 Outer	100	0	289	0	Branches 10, 11 300	
3B2 walls	200	0	928	0	970	
3C2 removed	300	0	1428	0	1515	
4A	100	0	Branch 13 0	0	Branch 27 0	
4B	200	0	2344	0	57	
4C	300	0	4004	0	810	
5A	100	0	1281	0	1026	
5B	200	0	2515	0	1843	
5C	300	0	3657	0	2544	

^aAir potentially contaminated with radioactive materials.^bCombined potentially contaminated air and uncontaminated air.

In analyzing case 2, which involved the pathway from the CPC through the adjoining EDR to the atmosphere, it was inappropriate to simulate removal of the exterior building walls and doors, since the 3-ft 3-in.-thick walls of the EDR are the exterior building walls at this point and would not be expected to fail under any tornado loadings. Accesses to the EDR from the outside are provided by a door and by a plywood-covered duct, which would be expected to fail under tornado-induced forces, and are modeled as removed for purposes of analysis.

As indicated in Table 5.2 for case 2, substantial volumes of air are predicted by TVENT to be released from the CPC through the unfiltered EDR pathway for all three tornadoes postulated. However, as will be discussed in Part II, although significant radiation levels have been measured in the CPC, these readings are caused by radioactive materials in equipment in the cell, and very little resuspendable or dispersible radioactive material is present in the CPC. Based on this conclusion, it was determined that unless a predicted release from the CPC could contain airflow from the GPC, the cases involving air discharges from the CPC alone were not considered to have a radioactive release potential, that is, cases 2A and 2B. In case 2C, 45 ft³ of air from the GPC could be included in the discharge from the CPC; however, this volume was not considered to have significant potential for release from the GPC to require further analysis based on the minimum criteria of 7700 ft³ of air.

For case 3, involving the pathway through manipulator and fire protection ports in the GPC and adjoining minicell, the case was analyzed with the exterior walls and doors both intact and removed. Tornado-induced forces would remove the covers over ports in the cell wall, creating an unfiltered pathway for air to flow into the operating aisle of the GPC. The operating aisle adjoins the main building stairwell, which has doors and openings to the outside, and any release to the operating aisle is considered to be a release to the atmosphere.

As shown in Table 5.2, releases through the GPC to operating aisle pathway to the atmosphere were predicted by TVENT to be less than the required 2100 ft³ for all the subcases considered. This is due primarily to the fact that openings from the cell to the operating aisle are very small compared with the sizes of other airflow pathways from the GPC; thus, resistance to airflow through the manipulator and fire protection ports is much higher than through the exhaust duct and the hatch to the PMC, and air tends to take the path of least resistance. Based on the low predicted volumes of air released through the GPC to operating aisle pathway, it was determined that case 3 (all subcases) did not present a hazard potential to the environment, and no further analysis was required.

For case 4 which involved a release of air from the GPC exhaust duct through the adjoining MSM building exhaust duct to the atmosphere, in postulating this release pathway, the MSM building walls and roof are

assumed to collapse upon tornado impact, causing damage to the MSM exhaust duct, which provides a pathway for air to be vented to the atmosphere. Without collapse of the building walls and damage to the exhaust duct, no pathway with potential for releasing air from the cells to the atmosphere is present; thus it is inappropriate to analyze case 4 with the exterior building walls and doors intact.

As shown in Table 5.2, the TVENT predicted volumes of air released from the GPC for cases 4A-4C are substantially less than the 7700-ft³ minimum; thus these subcases do not present a hazard potential, and no further analysis was required.

At the request of the NRC, an additional case was analyzed which considered the failure of the blower system for the exhaust blowers and of the emergency backup power system. The ventilation system was analyzed with all of the manipulator and other ports in the cell walls sealed, with the MSM building walls removed because of the building's proximity to the blowers and power supply, and with the blowers inoperative. Analysis of this case, denoted case 5, with TVENT, for 100-, 200-, and 300-mph tornadoes predicted that significant volumes of unfiltered air would be released from the GPC through the MSM building exhaust duct to the atmosphere. The volumes released from the GPC through the ventilation exhaust duct (represented by branch 13 in the schematic model) are as follows: case 5A, 1281 ft³; case 5B, 2515 ft³; case 5C, 3657 ft³. These volumes are less than the required 7700 ft³; therefore, further analysis was not required for this case for radioactive materials.

Another case was also analyzed at the request of the NRC to predict performance of the ventilation system under tornado accident conditions if all the ports in the cell walls were permanently sealed. Securing the ports is a method proposed to ensure containment provided by the head-end cells during a tornado strike. Analysis of this case with TVENT indicated that with all ports into the cells sealed to resist a pressure differential of at least 36.3 in. H₂O (1.3 psi), the total pressure drop of the largest tornado considered, there would be no discharge of air to the atmosphere through unfiltered pathways.

5.2 Cases with Potential for Transport of Radioactive Material

As discussed in Sect. 5.1, four of the twenty-one cases analyzed have potential for releasing significant amounts of radioactive materials from the head-end cells: Cases 1B1, 1C1, 1B2, and 1C2. Releases from the CPC alone are not considered to have a significant potential.

The cases identified as having a potential for releasing significant quantities of radioactive materials are the following:

1. case 1B1, PMC manipulator pathway for 200-mph tornado with exterior walls intact;
2. case 1C1, PMC manipulator pathway for 300-mph tornado with exterior walls intact;
3. case 1B2, PMC manipulator pathway for 200-mph tornado with exterior walls destroyed;
4. case 1C2, PMC manipulator pathway for 300-mph tornado with exterior walls destroyed.

These cases were analyzed further to determine the amounts of radioactive materials contained in postulated releases from the facility.

The next step required in determining quantities of radioactive materials contained within the air released from the cells is the prediction of tornado-induced air velocities within the cells. This procedure, discussed in Sect. 6, utilizes input from the TVENT analysis in the form of transient airflows and average velocities at cell boundaries. Pathways through which air can flow into and out of each cell are designated as branches in the cell exhaust model, shown previously in Fig. 4.4. Flows through these branches are considered to be flows at the boundaries of each cell, since TVENT does not model airflows within the cells.

Summaries of transient airflows generated within the facility under tornado accident conditions as estimated by TVENT are presented in the following subsections as plots of flow rates as a function of time.

5.2.1 Case 1. PMC manipulator port pathway

Airflows in branches 1, 2, 3, and 4 representing the PMC manipulator port pathway with the building walls intact, are shown in Figs. 5.1 and 5.2 for 100-, 200-, and 300-mph tornadoes, cases 1A1, 1B1 and 1C1. Sharp peaks in the flow rates at 2.0 s or less indicate times at which differential pressures across the manipulator covers reach a specified point, causing cover dislodgement. Negative values for the flows indicate reversal of direction from the directions of normal airflow before the tornado strikes. Normal flow directions are indicated in Fig. 4.4, the schematic model of cell exhaust pathways.

In case 1, during the 10-s duration of the tornado at the facility, the flow of air reverses direction in branches 1, 2, and 3 and flows out the ventilation supply path. Note that during this reversal, flow also reverses in branch 4, the open hatch between the PMC and the GPC,

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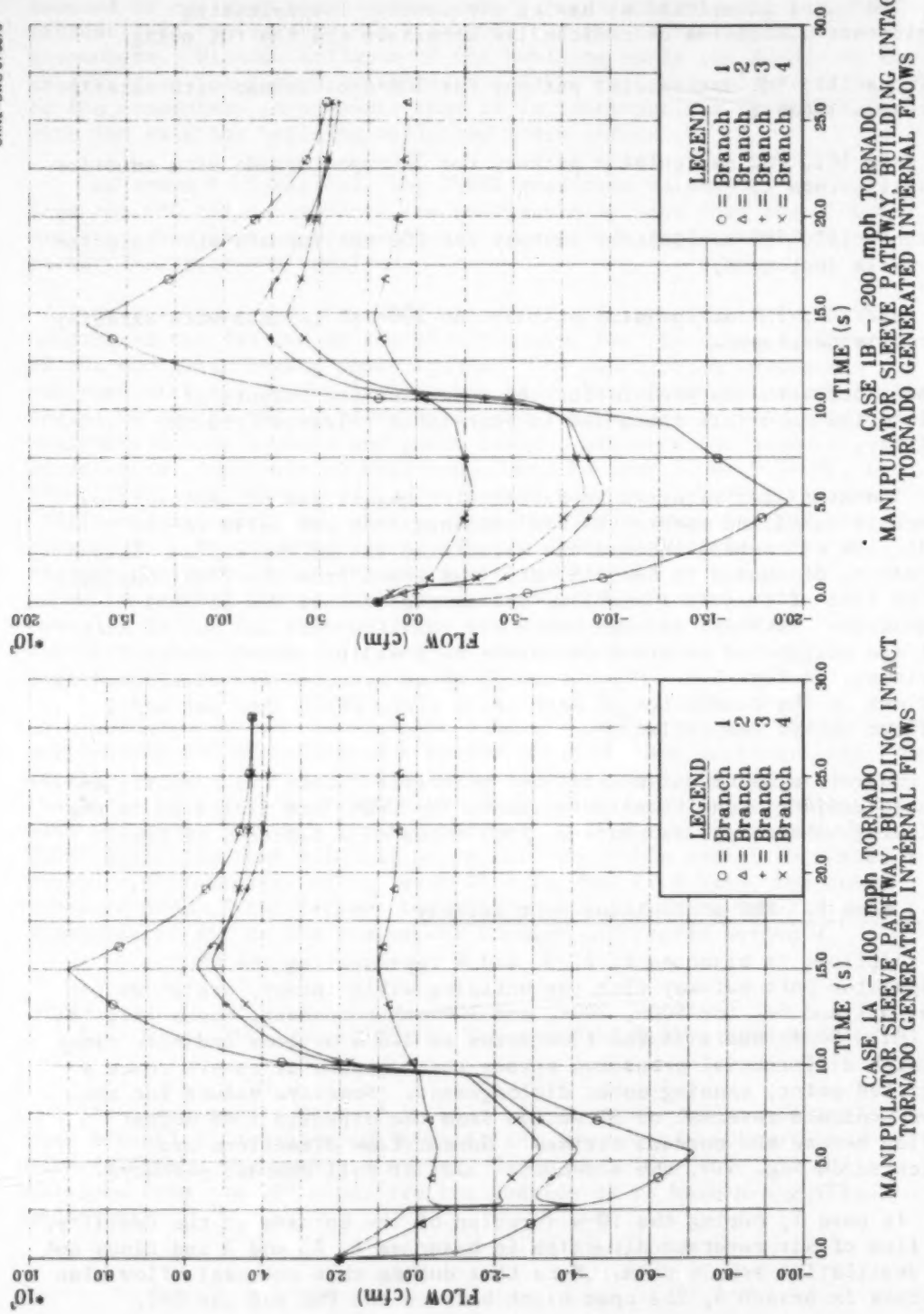


Fig. 5.1. Tornado-generated airflows in manipulator sleeve pathway for case 1A1 (100-mph tornado) and case 1B1 (200-mph tornado) as predicted with TVENT. Exterior building walls intact.

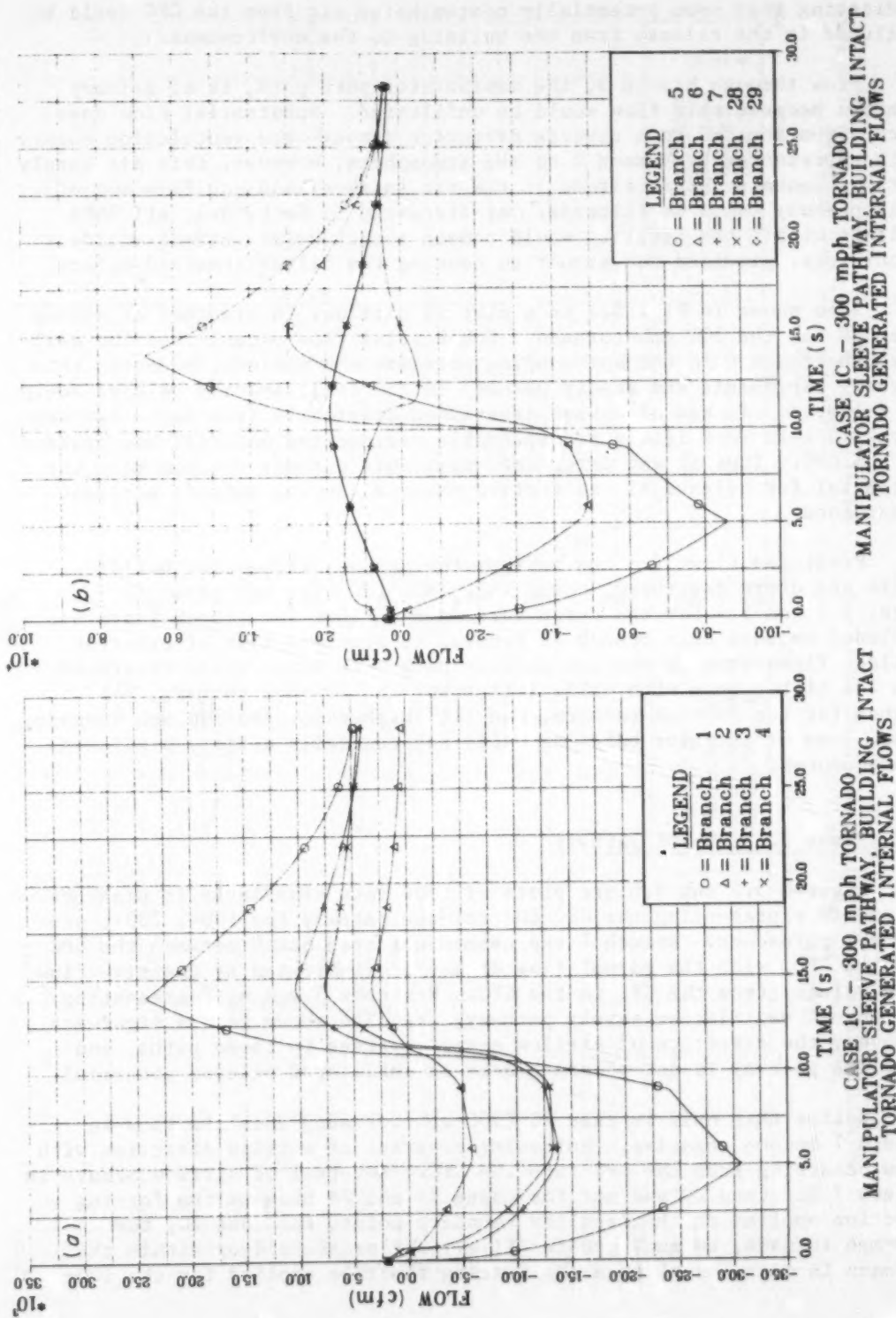


Fig. 5.2. (a) Tornado-generated airflows in manipulator sleeve pathway for case 1C1 (300-mph tornado). (b) Tornado-generated airflows in branches leading into chemical process cell for case 1C1 (300-mph tornado).

indicating that some potentially contaminated air from the GPC could be included in the release from the building to the environment.

Flow through branch 3, the manipulator port path, is of primary concern because this flow would be unfiltered. Substantial flow does occur from the PMC in a reverse direction through the ventilation supply path represented by branch 2 to the atmosphere; however, this air supply pathway contains HEPA filters at the air intakes, and any flow out of this pathway would be filtered. As discussed in Sect. 3.2, all HEPA filters within the facility would remain intact under tornado accident conditions, provided the structure housing the filter remained intact.

Also shown in Fig. 5.2 is a plot of airflows in branches adjoining the CPC for the 300 mph tornado. Substantial flow occurs from the cell through branch 6 to the surrounding corridor and ambient; however, this pathway represents the supply pathway to the cell, and any release would be filtered. It had also been determined previously (see Sect. 5.1 and Part II) that very little resuspendable radioactive material was present in the CPC. Thus it was determined that this pathway did not have the potential for release of radioactive material during tornado accident conditions.

Predicted flows for the manipulator pathway with outer building walls and doors destroyed, cases 1A2, 1B2, and 1C2, are given in Figs. 5.3 and 5.4 for the three tornadoes. Flows for branch 1 are not included because this branch is removed to simulate loss of exterior walls. Flows through the manipulator path with outer walls destroyed are 25% higher than with walls intact for the 100-mph tornado, 94% higher for the 200-mph tornado, and 111% higher for the 300 mph tornado; thus, loss of exterior building walls substantially affects predicted consequences.

5.2.2 Case 2. CPC-EDR pathway

Figures 5.5 and 5.6 are plots of flow rate transients in branches 28 and 29 representing the CPC-EDR release pathway for 100-, 200-, and 300-mph tornadoes. Branch 7 represents the open hatch between the CPC and the GPC, with the normal flow direction (indicated by positive flow rate values) from the CPC to the GPC. Branches 5 and 6, representing the normal ventilation supply pathway, are also shown in the figures; however, the direction of airflow never reverses in these paths, and thus the pathway is not of concern as an unfiltered release potential.

Notice that only in case 2C (300-mph tornado) does the flow in branch 7 become negative, indicating reversal of airflow direction with flow occurring from the GPC into the CPC. Reversal of airflow occurs in branch 7 for case 2C and not for cases 2A and 2B because the forcing function applied at the facility boundary points for case 2C, the 300-mph tornado, is much greater (i.e., the pressure drop within the tornado is much lower) than the forcing function applied for the 100-

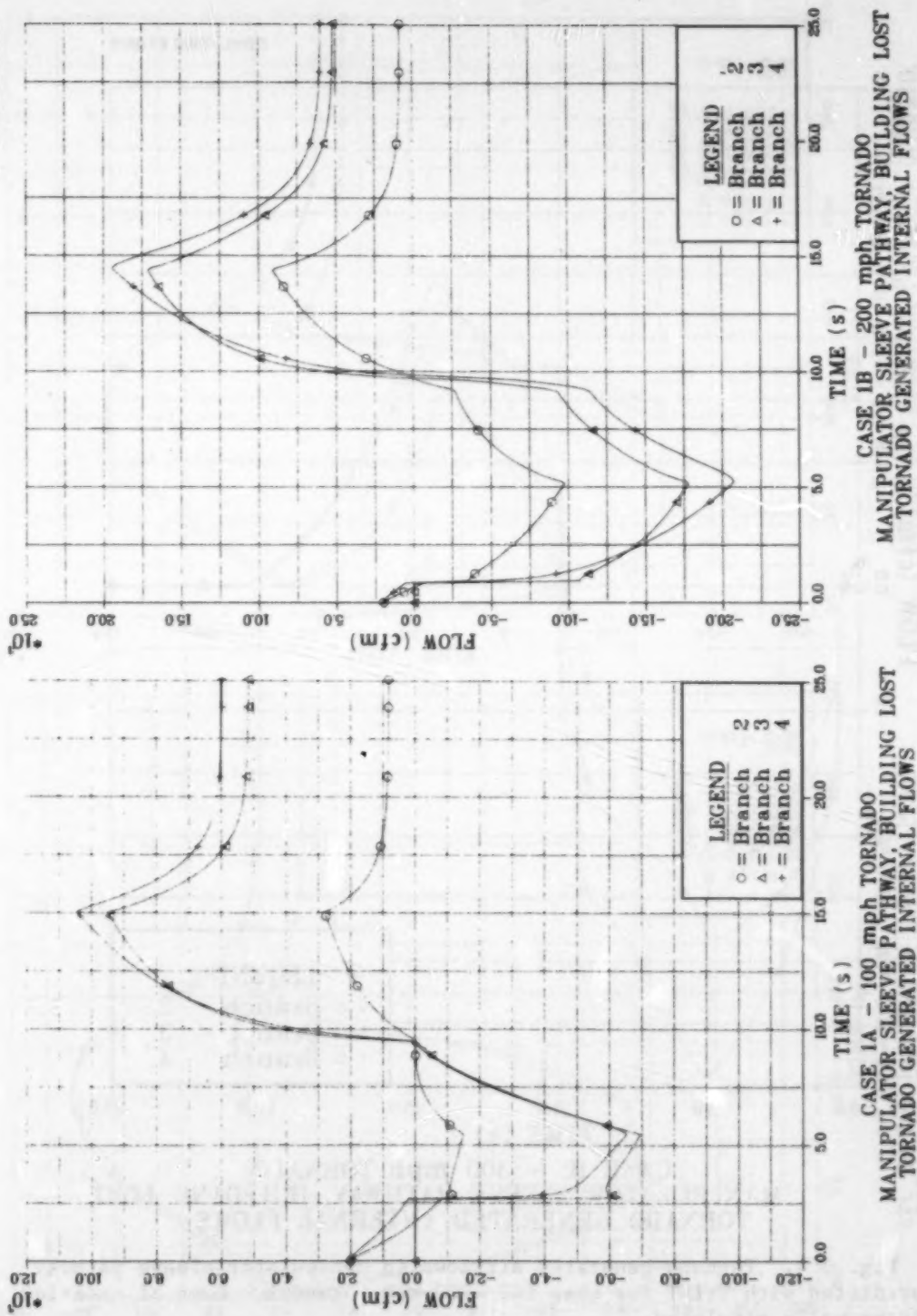
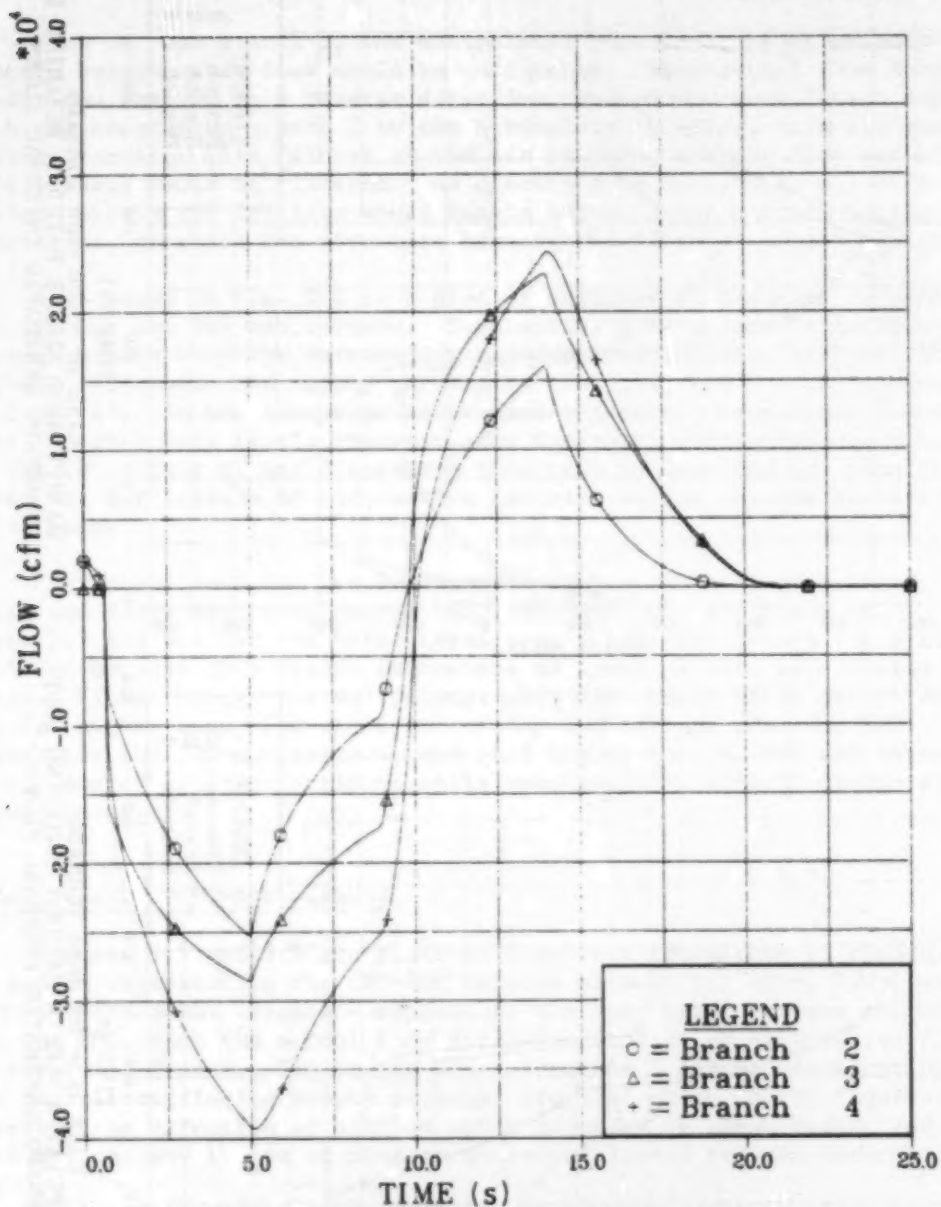
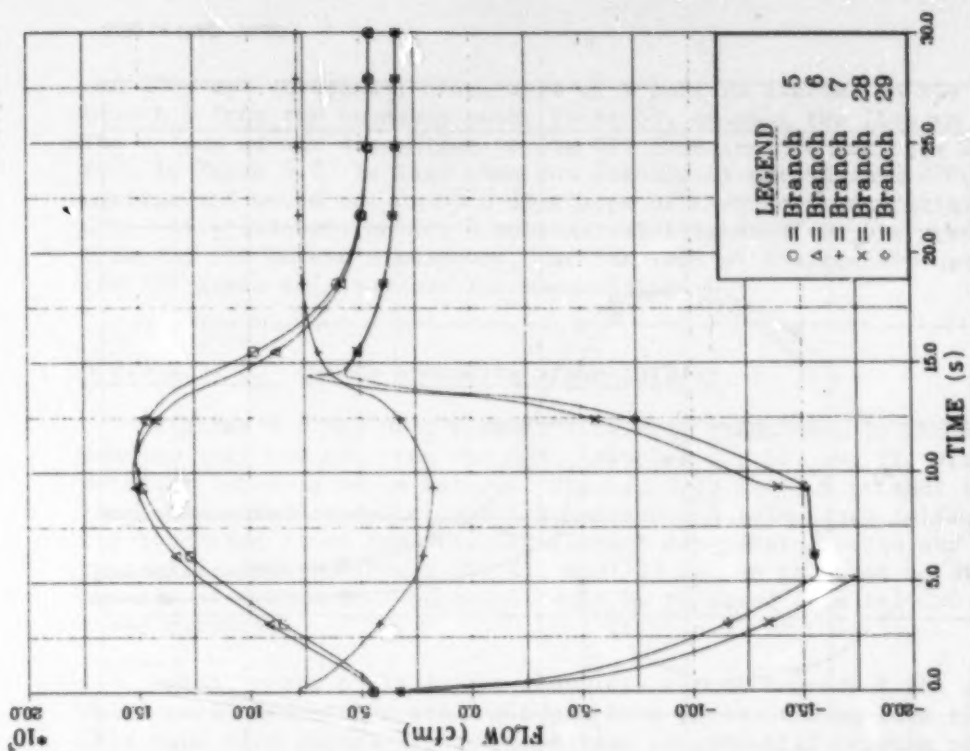


Fig. 5.3. Tornado-generated airflows in manipulator sleeve pathway with loss of exterior building walls simulated for case 1A2 (100-mph tornado) and case 1B2 (200-mph tornado). Airflows predicted with TVENT.

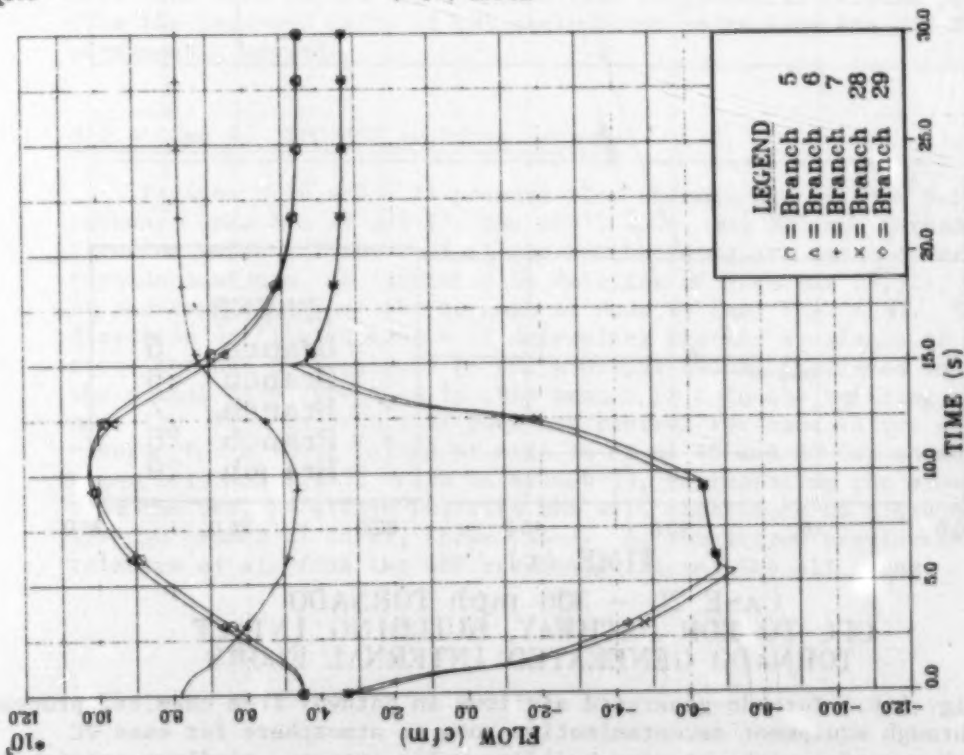


CASE 1C - 300 mph TORNADO
MANIPULATOR SLEEVE PATHWAY, BUILDING LOST
TORNADO GENERATED INTERNAL FLOWS

Fig. 5.4. Tornado-generated airflows in manipulator sleeve pathway as predicted with TVENT for case 1C2 (300-mph tornado). Loss of exterior building walls simulated.

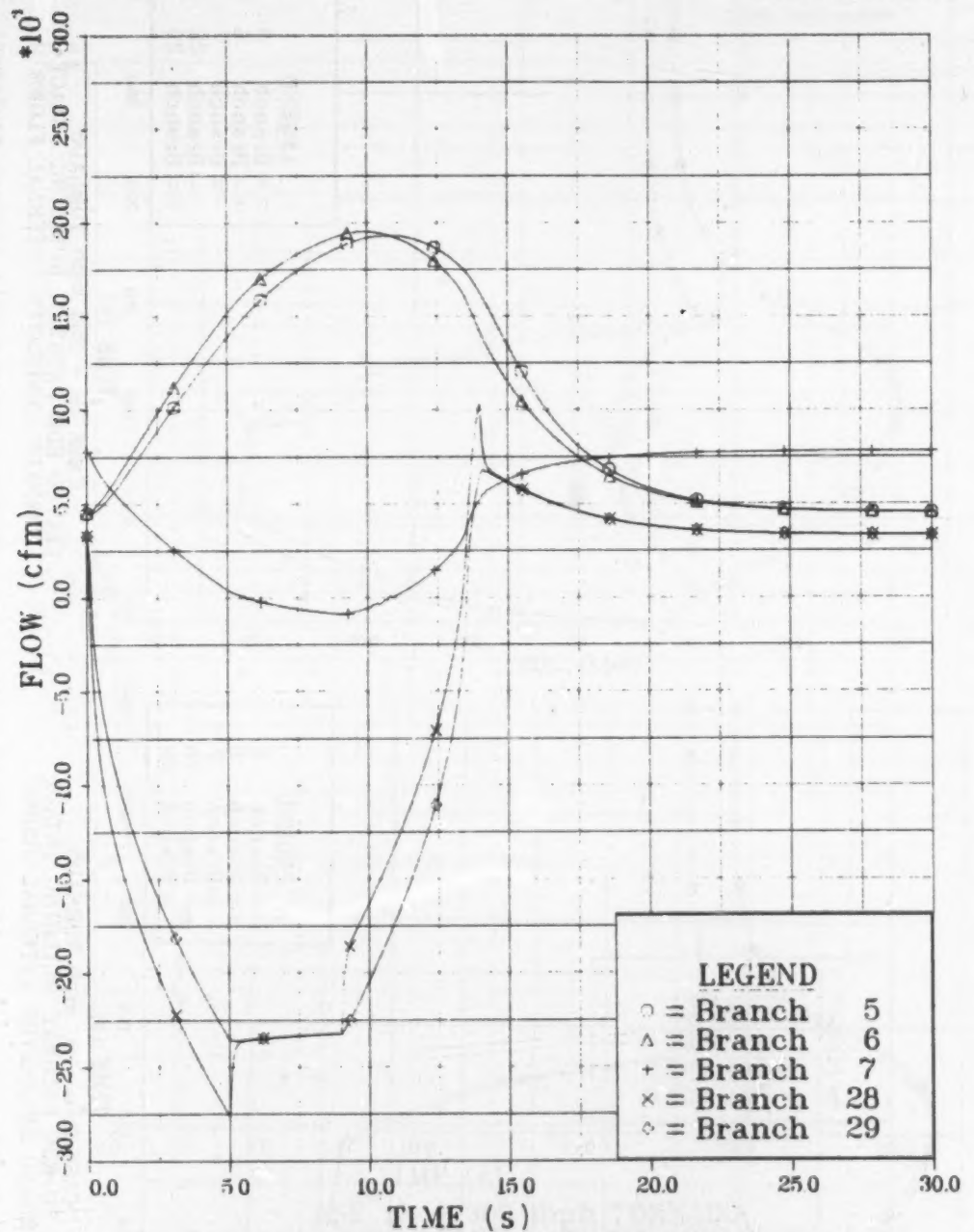


CASE 2A - 100 mph TORNADO
CPC TO EDR PATHWAY, BUILDING INTACT
TORNADO GENERATED INTERNAL FLOWS



CASE 2B - 200 mph TORNADO
CPC TO EDR PATHWAY, BUILDING INTACT
TORNADO GENERATED INTERNAL FLOWS

Fig. 5.5. Tornado-generated airflows in pathway from chemical process cell through equipment decontamination room to atmosphere for case 2A (100-mph tornado) and case 2B (200-mph tornado). Exterior building walls intact. Airflows predicted with TVENT.



CASE 2C - 300 mph TORNADO
CPC TO EDR PATHWAY, BUILDING INTACT
TORNADO GENERATED INTERNAL FLOWS

Fig. 5.6. Tornado-generated airflows in pathway from chemical process cell through equipment decontamination room to atmosphere for case 2C (300-mph tornado) with exterior building walls intact. Airflows predicted with TVENT.

and 200- mph tornadoes; thus, more of a pull is exerted on the flow in branch 7 from the boundary point (node 5), causing the flow to reverse. The volume of air discharged to the CPC from the GPC for case 2C (45 ft³ in Table 5.2) is less than the previously established 7700-ft³ minimum and would not cause a discharge of radioactive material from the GPC. As previously noted, a substantial release of air is predicted from the CPC to the atmosphere, but the lack of dispersible material in the CPC makes this release inconsequential.

5.2.3 Case 3. GPC to operating aisle pathway

Figures 5.7 and 5.8a present flow rate transients in the branches leading into the GPC from the GOA, branches 10, 11, and 12, with the exterior building walls intact. Figures 5.8b and 5.9 present the same case with exterior building walls removed. As discussed in Sect. 5.1, the predicted flows from the GPC through manipulator ports and a fire protection port (branches 10, 11, and 12) are so low that no significant amounts of radioactive material could be released from the GPC through these pathways.

Again, sharp peaks in the flow rate curves represent the point at which cardboard covers are dislodged from ports leading into the GPC. This case also represents the condition of potential release pathways from the head-end cells if the manipulator ports from the PMC were permanently sealed.

5.2.4 Case 4. GPC-MSM building pathway

Figures 5.10 and 5.11 present flow through the GPC-MSM building pathway, branches 13 and 27, for 100-, 200-, and 300-mph tornadoes. Exterior walls and the roof of the MSM building are assumed destroyed by tornado loadings, as simulated by deletion of branches 23, 24, 25, and 26 and application of the tornado at node 24 (see Fig. 4.4). The direction of flow in branch 27 determines whether a release of air will occur through this pathway to the atmosphere. As indicated in Fig. 4.4, the normal flow direction in this branch is into the building toward node 12. Flow in branch 27 does not reverse for case 4A but does reverse for a short period of time in cases 4B and 4C (as shown in Figs. 5.10 and 5.11). Flow in branch 13, representing the exhaust duct from the GPC, is always positive and will contribute to a discharge through branch 27 in all three cases. As summarized previously, releases of air from the GPC are insignificant for all cases.

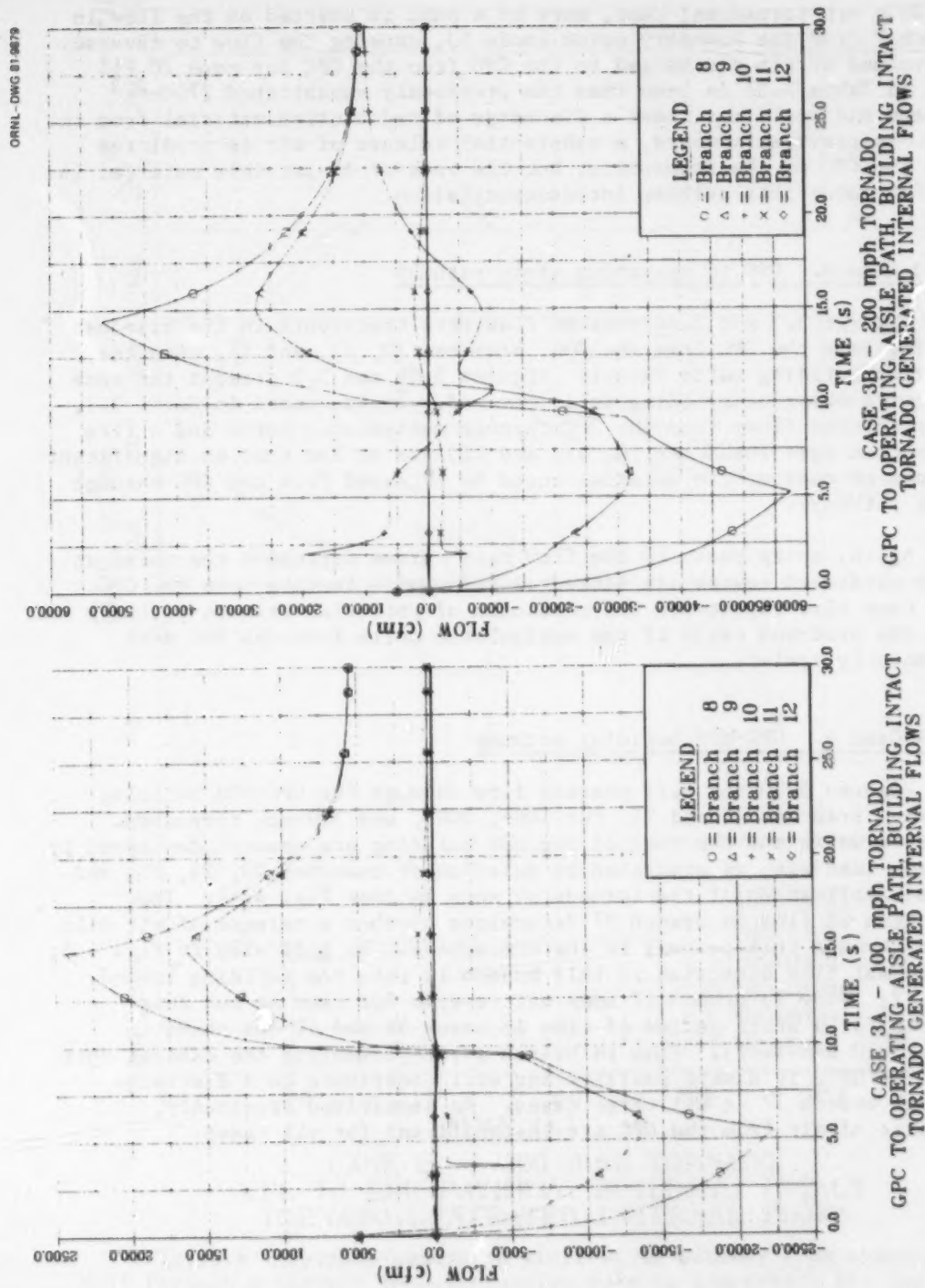


Fig. 5.7. Tornado-generated airflows in pathway from general-purpose cell through ports to the operating aisle, case 3, for 100- and 200-mph tornadoes as predicted with TVENT. Exterior building walls intact.

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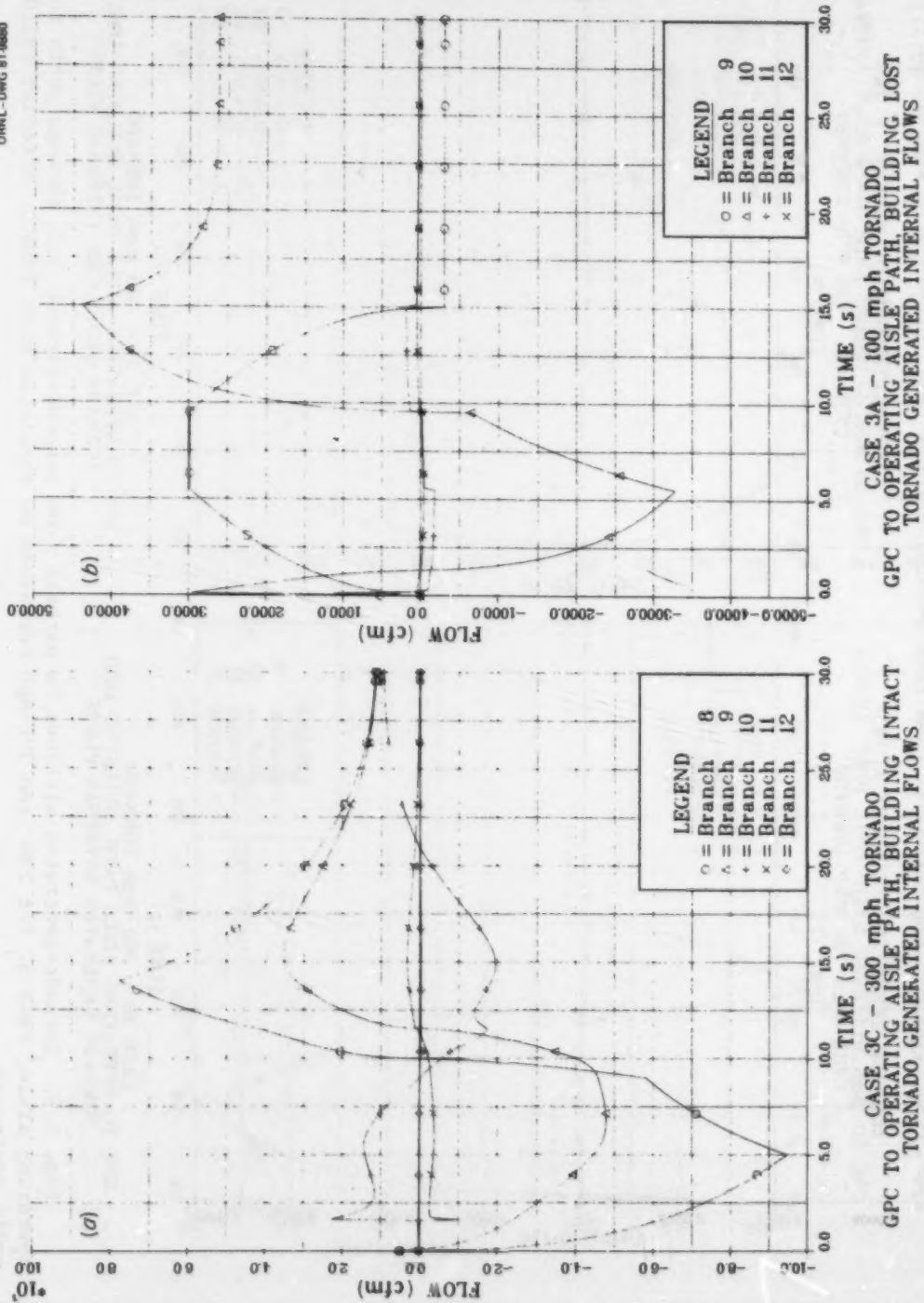


Fig. 5.8. Tornado-generated airflows in pathway from general-purpose cell through ports to operating aisle. (a) For 300-mph tornado with building intact; (b) for 100-mph tornado with building lost.

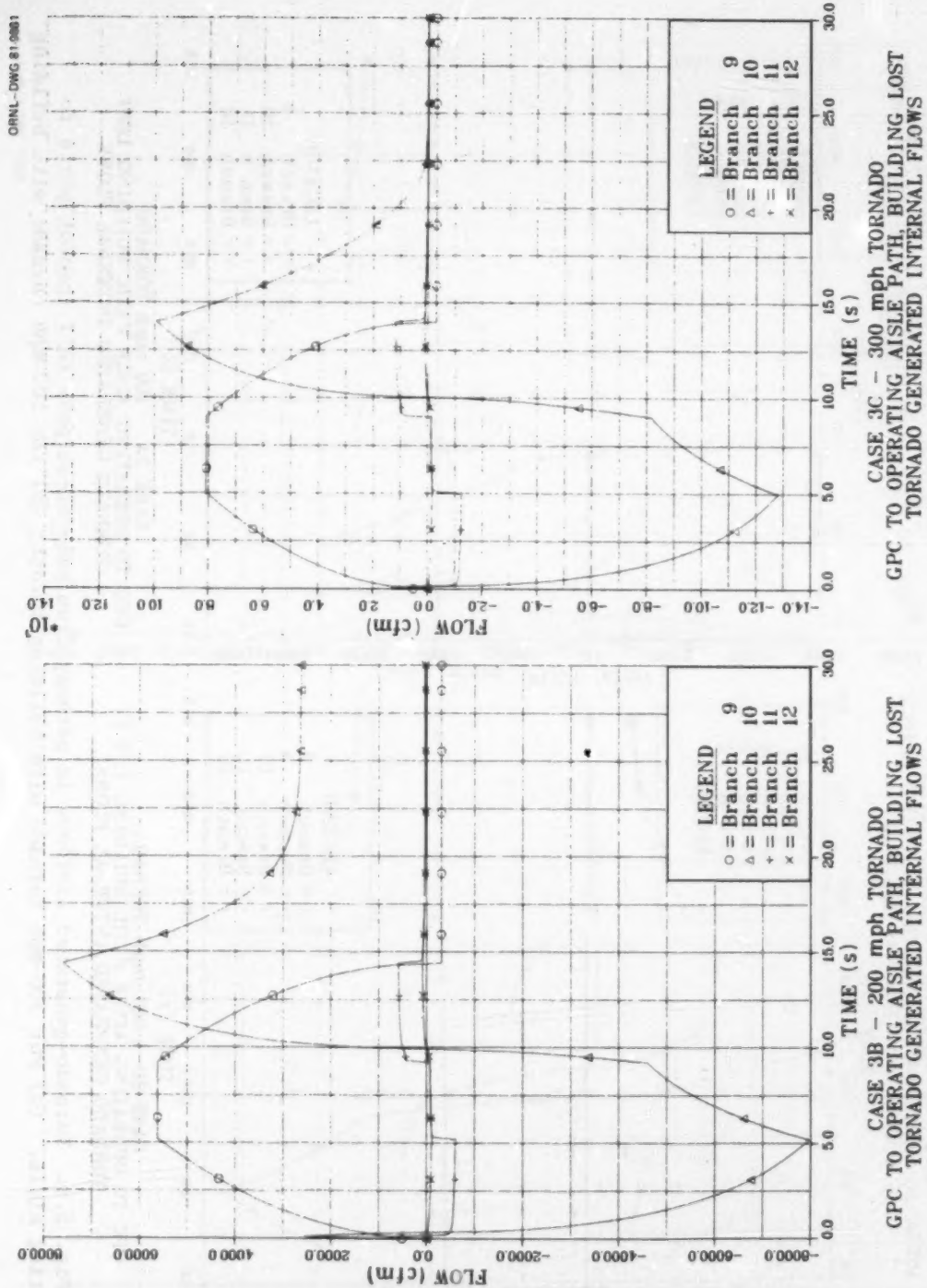


Fig. 5.9. Tornado-generated airflows in pathway from general-purpose cell through ports to operating aisle, case 3, for 200- and 300-mph tornadoes as predicted with TVENT. Exterior building walls destroyed.

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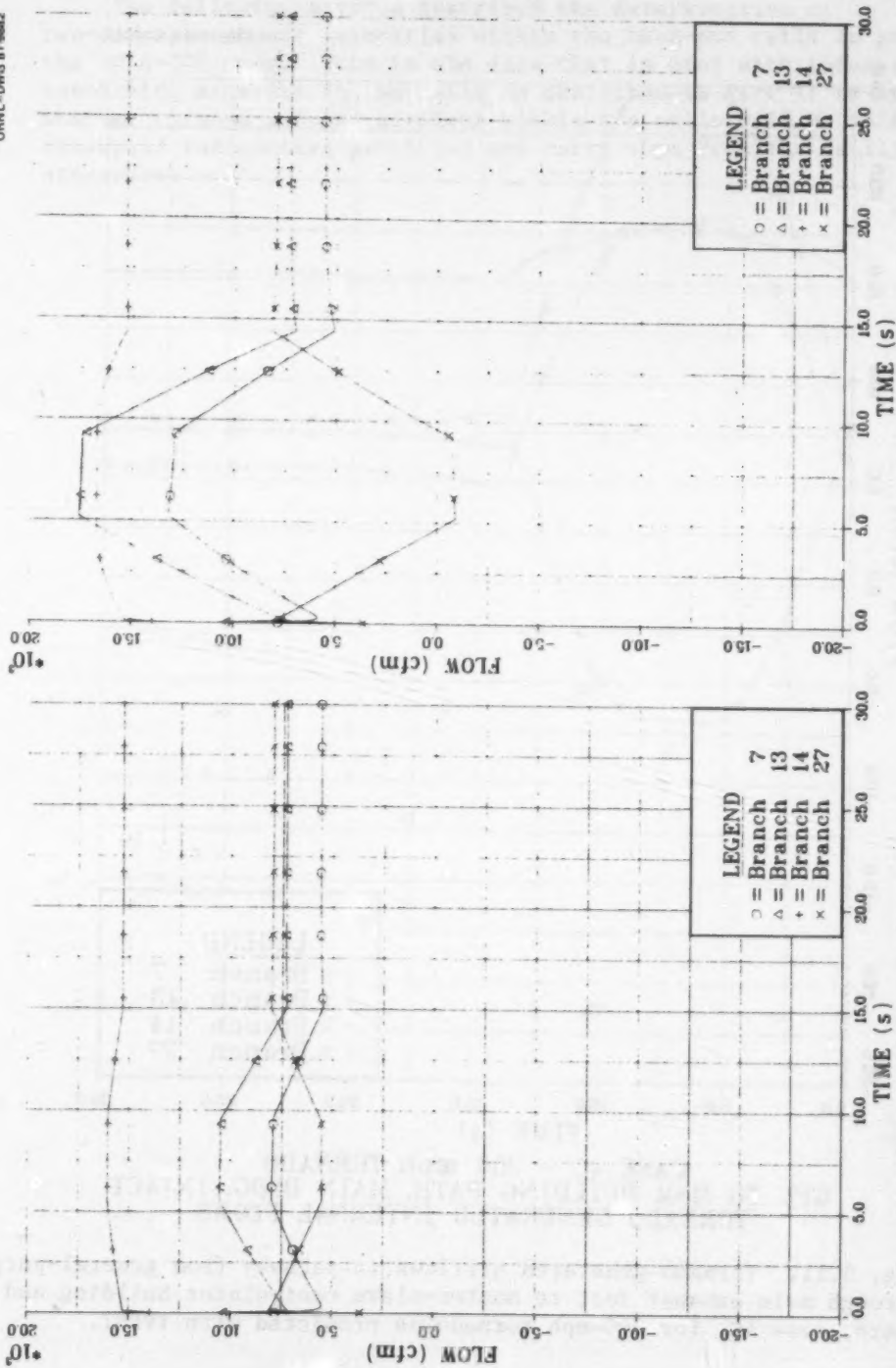
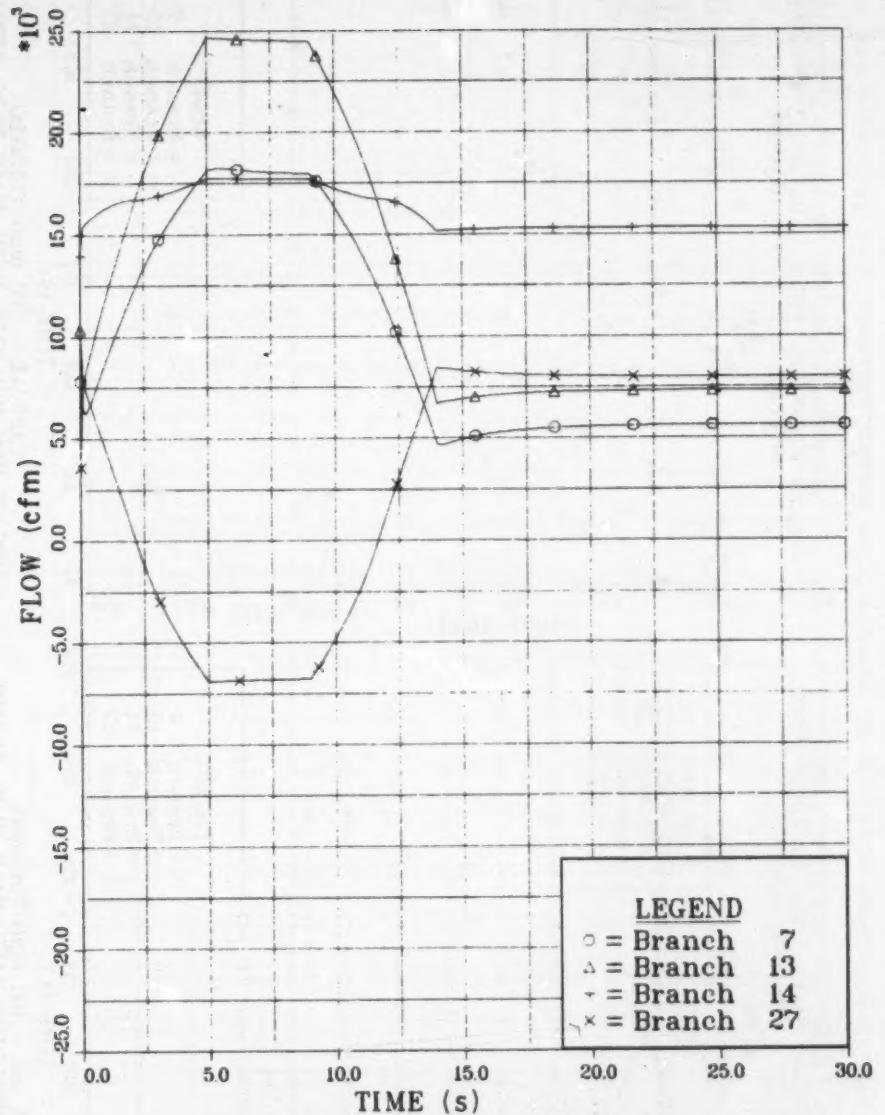


Fig. 5.10. Tornado-generated airflows from general-purpose cell through main exhaust duct to master-slave manipulator building and atmosphere, case 4, for 100- and 200-mph tornadoes. Airflows predicted with TVENT.

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CASE 4C - 300 mph TORNADO
GPC TO MSM BUILDING PATH, MAIN BLDG. INTACT
TORNADO GENERATED INTERNAL FLOWS

Fig. 5.11. Tornado-generated airflows in pathway from general-purpose cell through main exhaust duct to master-slave manipulator building and atmosphere, case 4C, for 300-mph tornado as predicted with TVENT.

The following section describes the determination of two-dimensional air velocities within the head-end cells as presented by the SOLA-ICE code. This is the data that is used with information concerning material in the cells as described in Part II to determine whether tornado-induced airflows within the cells will be sufficient to resuspend radioactive particles and carry them from the facility to the atmosphere.

6. TORNADO-INDUCED AIR VELOCITIES IN HEAD-END CELLS

In Sect. 5, cases 1B1, 1C1, 1B2, and 1C2 were identified as having the potential for significant radiological releases from the head-end cells under tornado accident conditions; additional analysis was required to determine the quantities of radioactive material in these releases.

An essential step in estimating amounts of material discharged is the determination of tornado-induced air velocities near contaminated surfaces of the head-end cells. As will be discussed in Part II, near-floor velocities above a certain magnitude can reentrain or resuspend radioactive particles which may eventually be released at the plant's atmospheric boundaries.

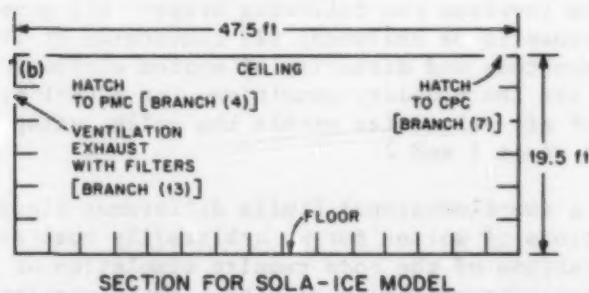
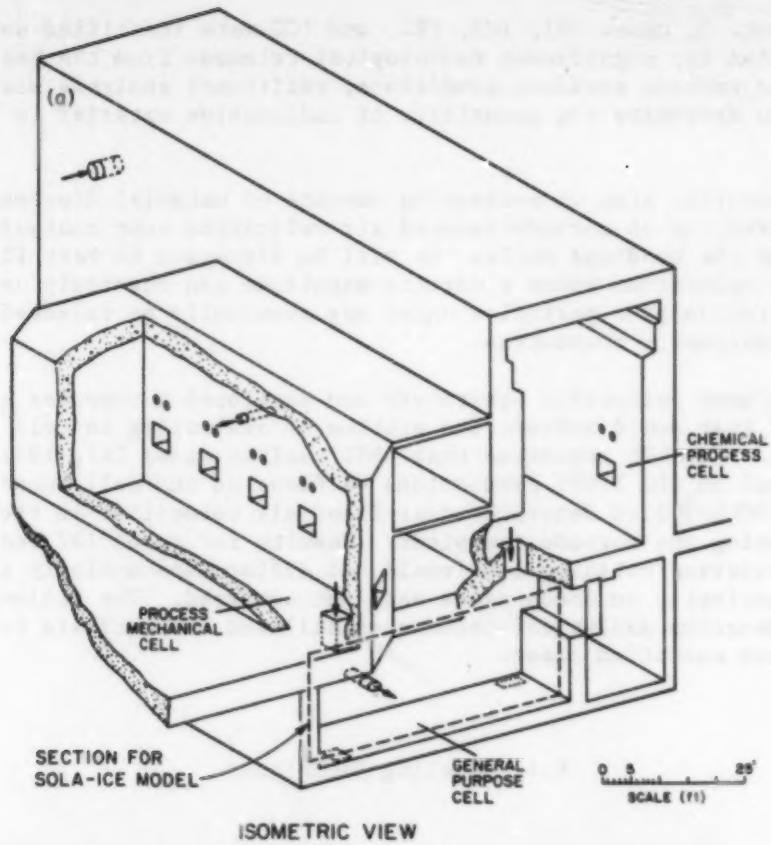
Los Alamos Scientific Laboratory had developed a computer code, SOLA-ICE,⁶ that would address the problem of evaluating in-cell velocities. The NRC requested that LASL analyze cases 1A1, 1B1, 1C1, and 4C based on the TVENT predictions of flows at the cell boundaries utilizing SOLA-ICE to determine near-floor air velocities in the PMC and the GPC during the tornado transient. Results for cases 1B2 and 1C2 with the exterior building lost would not differ substantially in the SOLA-ICE analysis, so these cases were not analyzed. The following sections describe analytical techniques utilized and analysis results for the four specified cases.

6.1 Modeling Techniques

The procedure for determining tornado-induced air velocities within the head-end cells involves the following steps: (1) geometrical modeling of the rooms to be analyzed; (2) conversion of TVENT output predicting the magnitude and direction of system airflows into velocities which are the boundary conditions for SOLA-ICE; and (3) calculation of air velocities within the cells, using SOLA-ICE based on the results of steps 1 and 2.

SOLA-ICE is a two-dimensional finite difference algorithm for solving the equations of motion for an arbitrarily compressible fluid.⁶ Dimensional limitations of the code require simulation of the effects occurring in a three-dimensional room with a two-dimensional model. The model used for the GPC (Fig. 6.1) is, essentially, a vertical slice through the cell along its length as indicated by the cross section shown below the isometric view. To simulate the effect of the ventilation exhaust duct (branch 13 in the TVENT schematic model) located in the front face of the cell shown in the isometric drawing,

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GPC

Fig. 6.1.(a) Isometric drawing of head-end cells; (b) SOLA-ICE model of general-purpose cell.

the duct was rotated 90° and translated so that all flow paths would be in the same plane (this procedure is described in ref. 4).

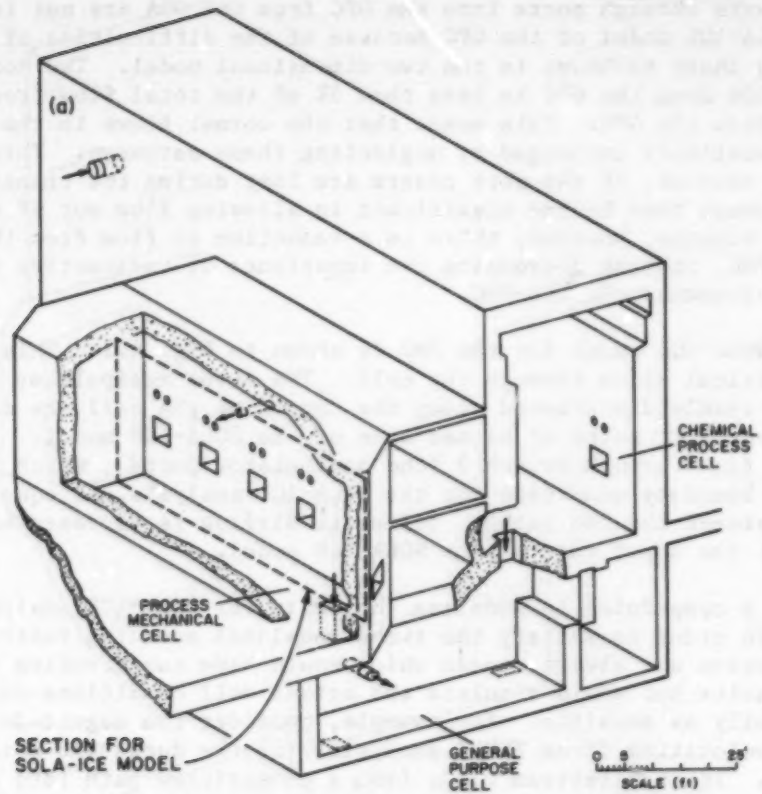
Pathways through ports into the GPC from the GOA are not included in the SOLA-ICE model of the GPC because of the difficulties of simulating these pathways in the two-dimensional model. The normal flow into the GOA from the GPC is less than 5% of the total flow from all pathways into the GPC. This means that the normal flows in the GPC remain essentially unchanged by neglecting these pathways. This is not the case, however, if the port covers are lost during the transient and these pathways then become significant in allowing flow out of the GPC. When this happens, however, there is a reduction in flow from the GPC into the PMC, thereby decreasing the importance of radioactive release to the environment via the PMC.

The SOLA-ICE model for the PMC is shown in Fig. 6.2. This model is also a vertical slice through the cell. The seven manipulator ports which are evenly distributed along the length of the cell are divided into two boundary paths on either side of the SOLA-ICE model. The TVENT predicted flow through branch 3 (the manipulator ports), which is input as a cell boundary condition for the SOLA-ICE analysis, is equally divided between the two paths. Inleakage airflow is represented by a pathway at the upper edge of the SOLA-ICE model.

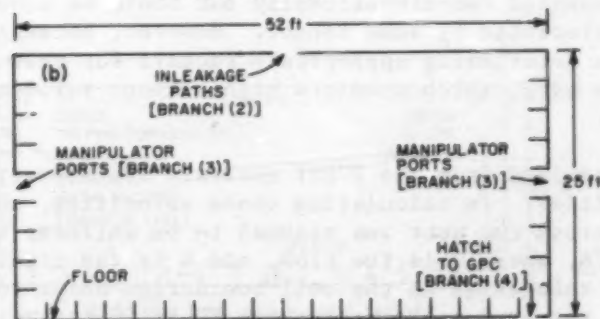
When a compromise in modeling the cells for SOLA-ICE analysis was required in order to satisfy the two-dimensional modeling restrictions, a modification was always chosen which would have conservative effects on the results but would simulate the actual cell conditions as realistically as possible. For example, consider the magnitude of the boundary velocities (from TVENT analysis) for the ducts and hatches into the cells. If an airstream flows from a constricted path into a larger volume, the airstream expands, reducing the velocity. This effect cannot be represented two-dimensionally but could be modeled by reducing the boundary velocities by some factor. However, because of difficulties in determining appropriate factors for this analysis, a factor of 1 was used, which predicts higher floor velocities than would actually occur.

Flows determined from the TVENT analysis are converted to cell boundary velocities. In calculating these velocities, the velocity distribution across the duct was assumed to be uniform; that is, velocity $v = Q/A$, where Q is the flow, and A is the cross sectional area. Average velocities at the cell boundaries under tornado conditions are required as input for the SOLA-ICE analysis.

Branches 4, 7, 12, and 13 represent the boundaries of the GPC. Transient velocities in these branches for cases 1B1 and 1C1 are shown in Fig. 6.3. Transient velocities in branches 2, 3, and 4, the boundaries of the PMC, are shown in Fig. 6.4 for cases 1B1 and 1C1.



ISOMETRIC VIEW



SECTION FOR SOLA-ICE MODEL

PMC

Fig. 6.2.(a) Isometric drawing of head-end cells; (b) SOLA-ICE model of process mechanical cell.

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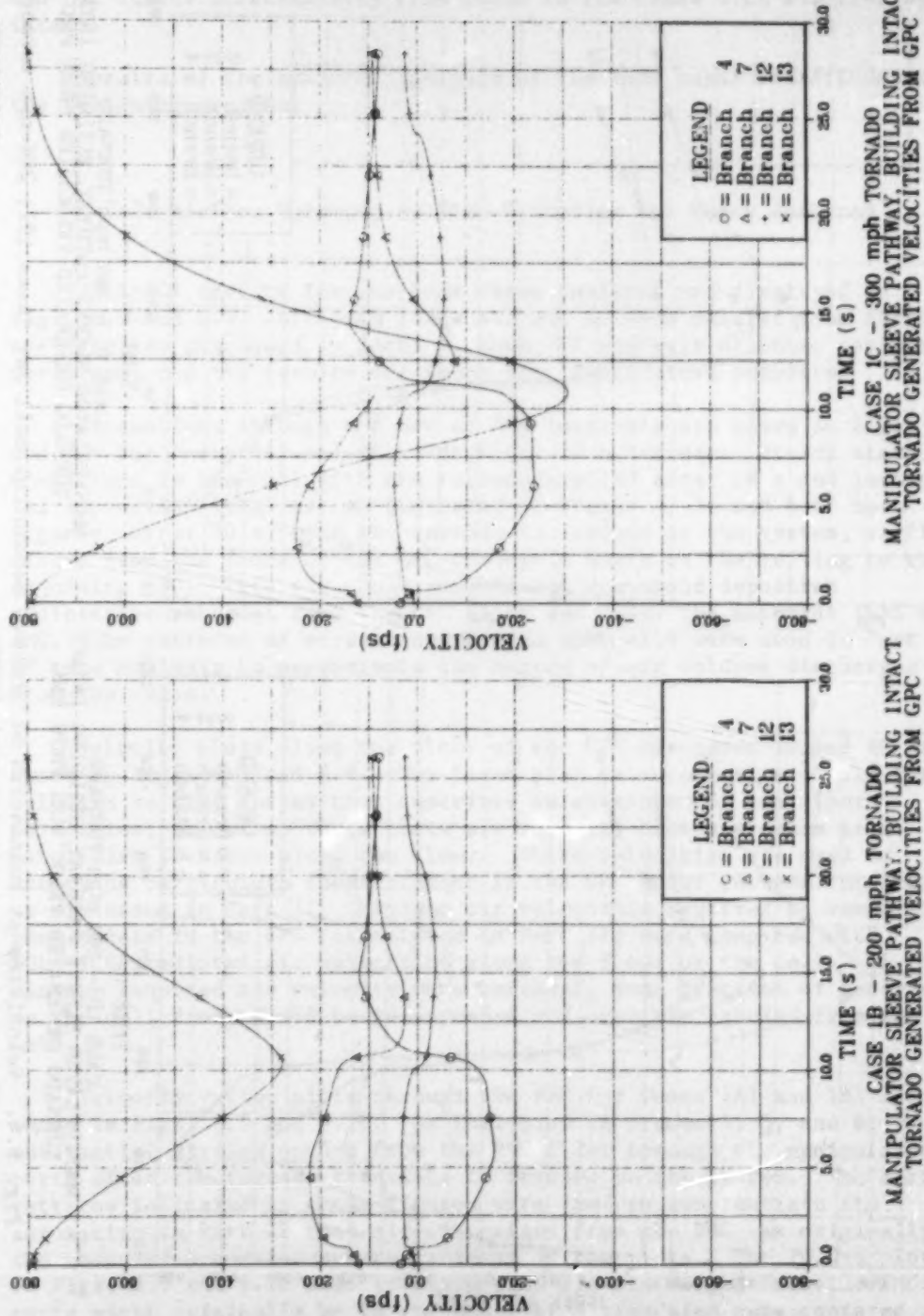


Fig. 6.3. Velocities at boundaries of general-purpose cell for cases 1B1, 200-mph tornado, and 1C1, 300-mph tornado, as predicted with IVENT.

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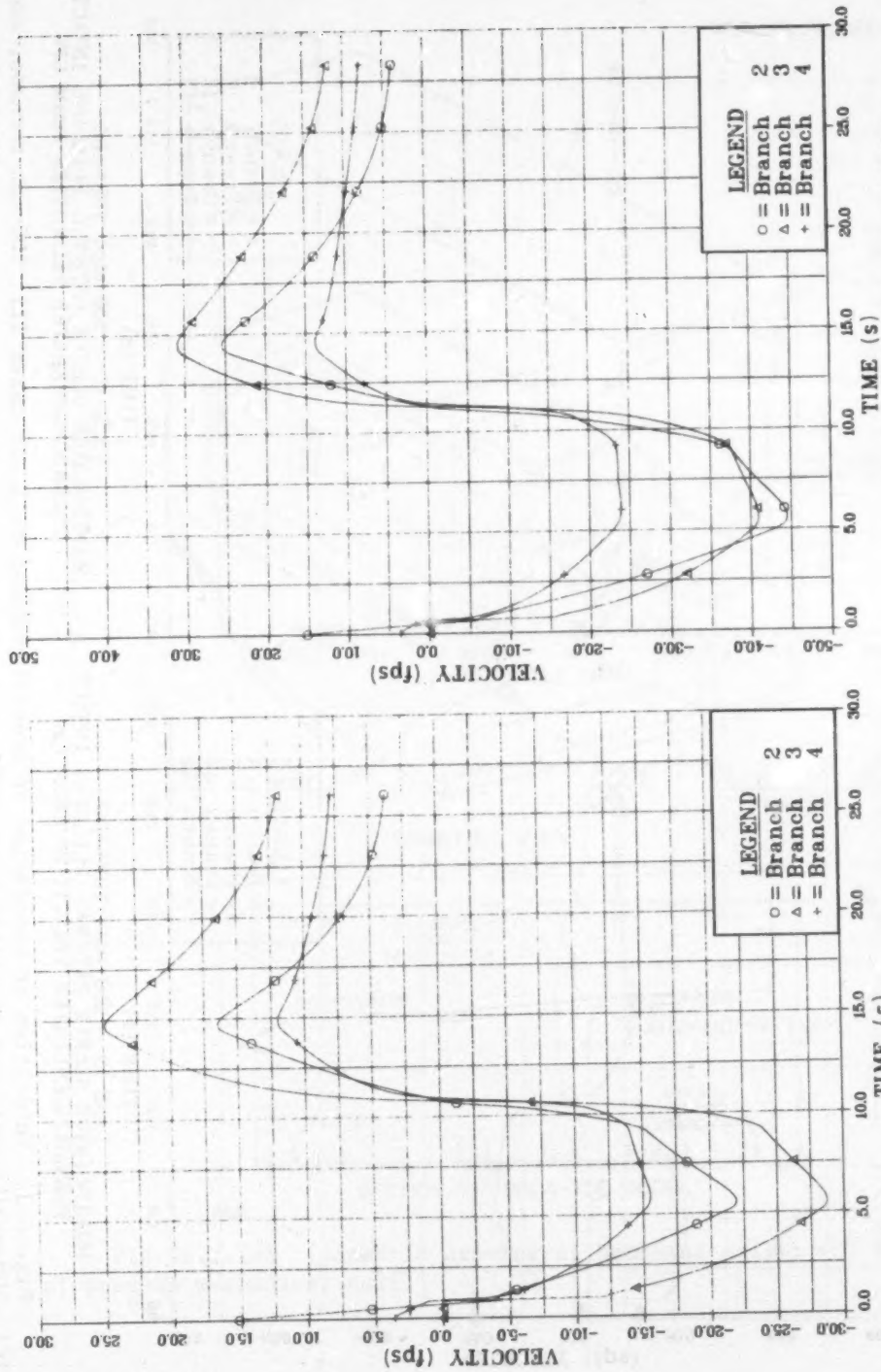


Fig. 6.4. Velocities at boundaries of process mechanical cell for cases 1B1, 200-mph tornado, and 1C1, 300-mph tornado, as predicted with TVENT.

Velocities in both cells for cases 1B2 and 1C2 with exterior walls lost did not differ substantially from those in the cases with exterior walls intact.

Results of the SOLA-ICE analysis of the four cases are discussed in the following section.

6.2 Airflow Velocity -- Time Histories for Cases Analyzed

SOLA-ICE results for the four cases analyzed are displayed in Figs. 6.3 and 6.4. Although cases 1A1 and 4C were deleted from further analysis, as discussed in Sect. 5, SOLA-ICE analysis of these cases was performed, and the results are shown for illustrative purposes.

Streamlines through the GPC at 5-s intervals are shown in Figs. 6.5 and 6.6 for cases 1A1 and 4C. The first 10 s represent steady state conditions in the cell with the tornado applied after 10 s and lasting for approximately 15 s. As indicated in frames 4, 5, and 6 of both figures, after 10 s, when the tornado is applied to the system, airflow occurs from the floor of the GPC through a hatch in the ceiling to the adjoining PMC. This air could potentially resuspend deposited radioactive material from the GPC floor and carry the material into the PMC. The patterns of streamlines within the cells were used in Part II¹ of this analysis to approximate the shapes of air volumes discharged from the cells.

Velocity plots along the floor of the GPC for cases 1C and 4C are shown in Figs. 6.7 and 6.8. The first plot is a composite of all the velocity vs time curves that describes an envelope for the floor velocities; the other three plots are velocity time histories at a particular location along the floor. These velocities are used to determine particulate reentrainment in the GPC under tornado conditions, as discussed in Part II. Minimum air velocities required to reentrain particulate in the GPC (calculated in Part II) were compared with SOLA-ICE-predicted air velocities along the floor of the cell. If the minimum required air velocity were exceeded, some fraction of material on the cell floor would be resuspended and possibly carried from the cell.

Velocity vector plots through the PMC for Cases 1A1 and 1B1 are shown in Figs. 6.9 and 6.10. As indicated in frames 4, 5, and 6, substantial airflow occurs from the PMC floor through the manipulator ports after the tornado transient is imposed on the system. The airflow patterns indicated in these figures were used to substantiate the assumption in Part II that air discharged from the PMC was originally in the shape of a quarter-sphere centered at the ports. The 20.0-s plots of Figs. 6.9 and 6.10 also indicate that air discharged from the PMC ports might originally be in the shape of a truncated cone centered at

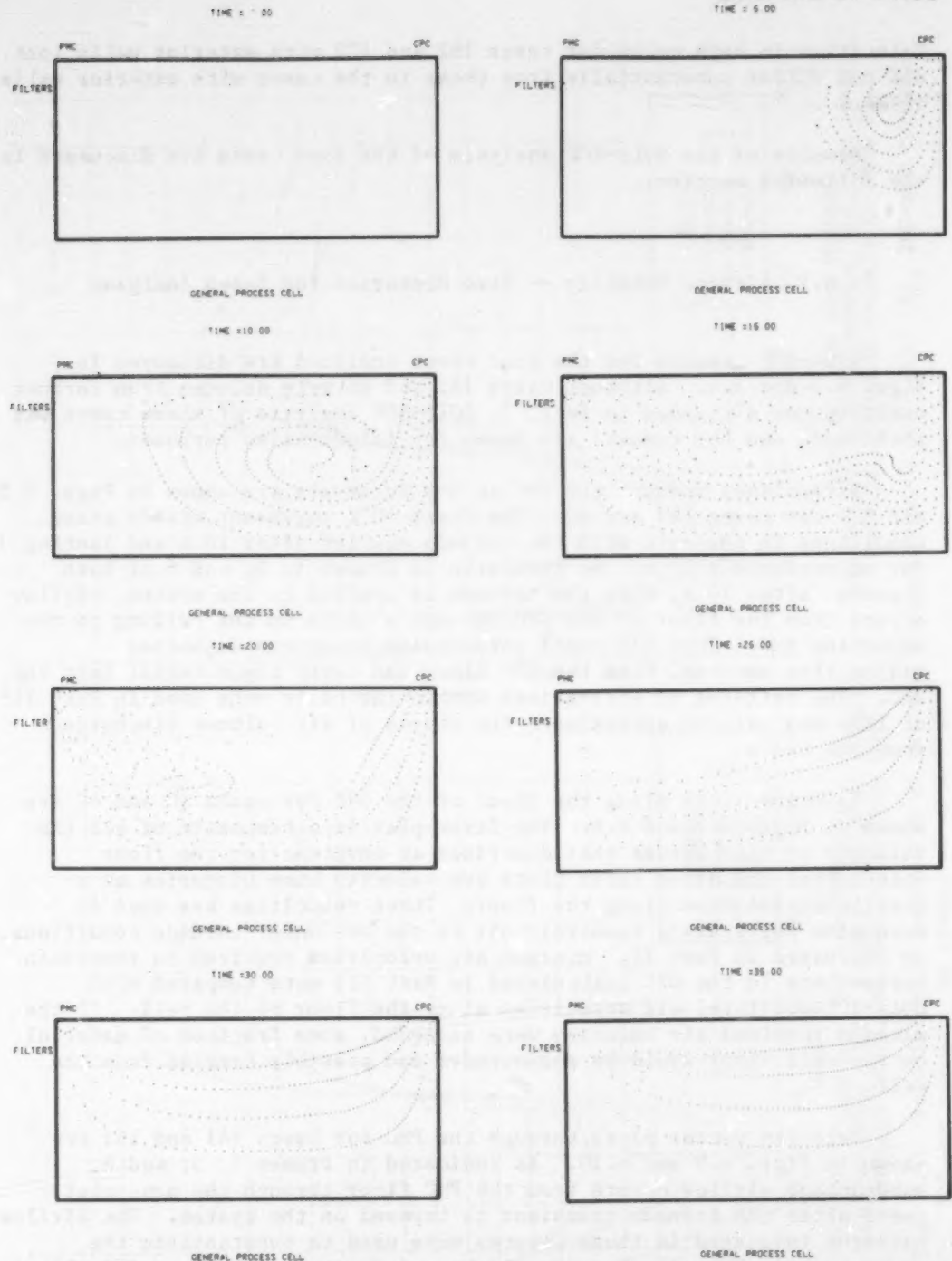
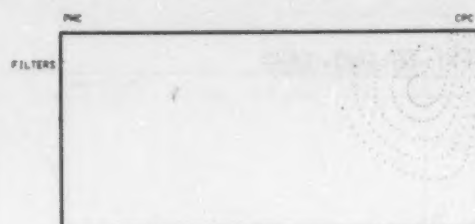
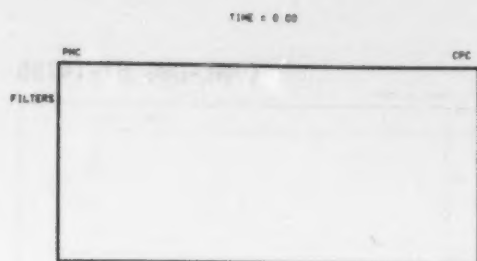


Fig. 6.5. Streamlines through general-purpose cell for case 1A1, 100-mph tornado, as determined by SOLA-ICE code. (Normal conditions from 0 to 10 s; tornado impact at 10 s.)

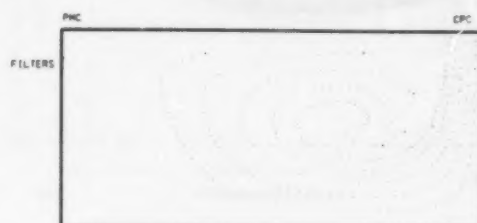
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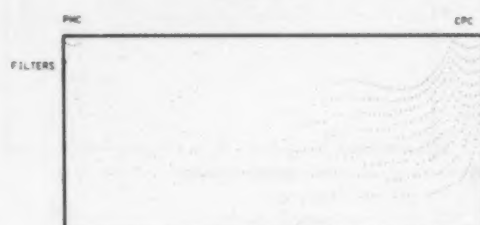
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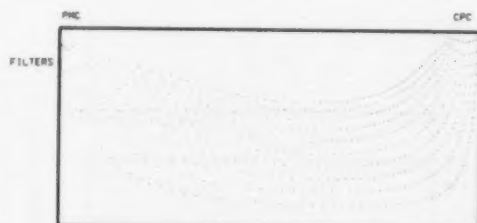
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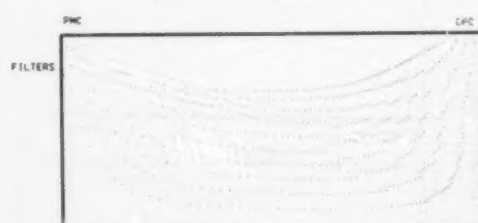
GENERAL PROCESS CELL

TIME = 20 00



GENERAL PROCESS CELL

TIME = 25 00



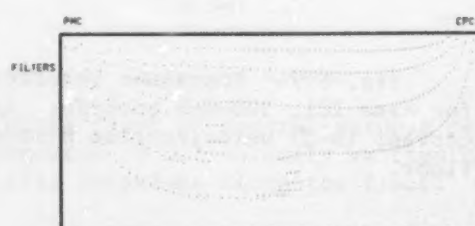
GENERAL PROCESS CELL

TIME = 30 00



GENERAL PROCESS CELL

TIME = 35 00



GENERAL PROCESS CELL

GENERAL PROCESS CELL

Fig. 6.6. Streamlines through general-purpose cell for case 4C, 300-mph tornado, as determined with SOLA-ICE code.

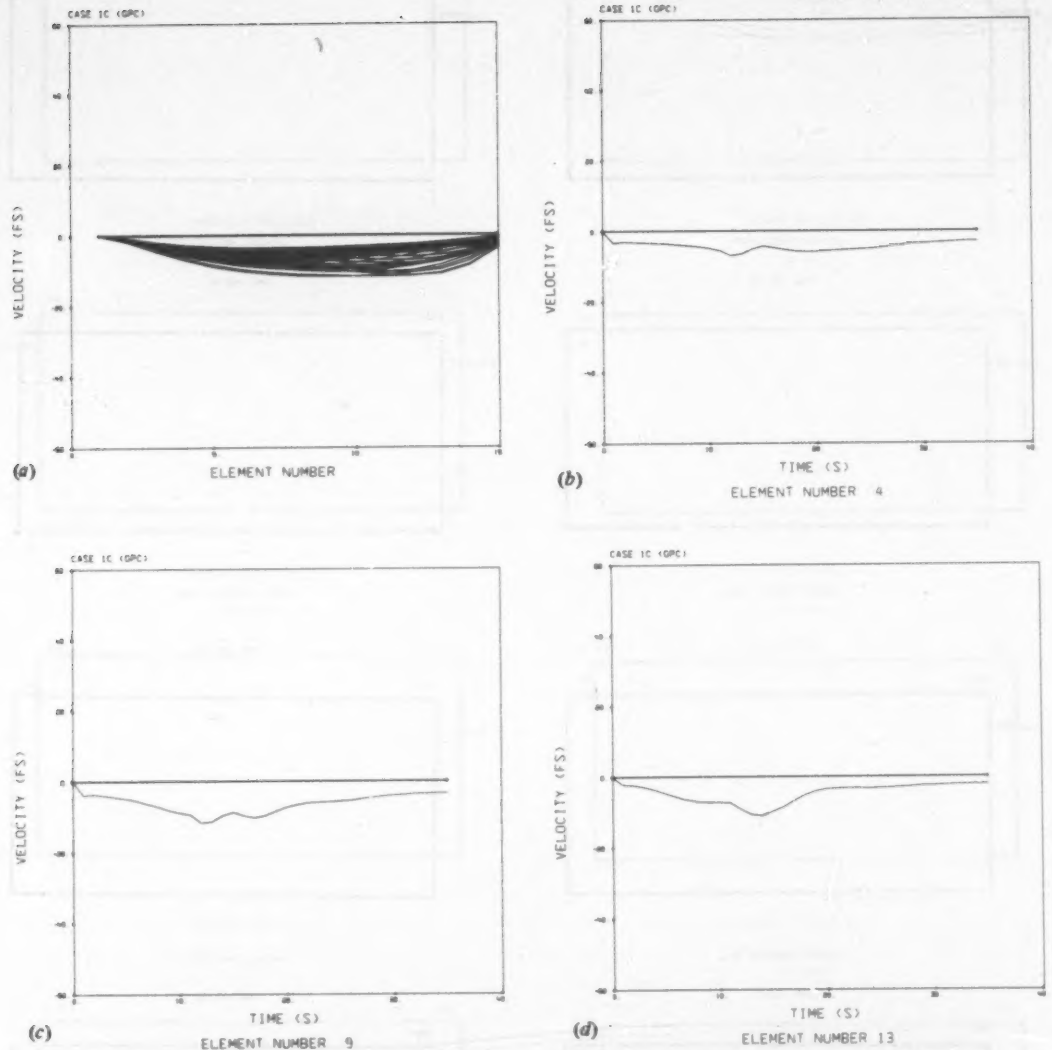


Fig. 6.7. Transient velocities along floor of general-purpose cell for case 1C1, 300-mph tornado. (a) Composite of all velocity vs time curves; (b-d) velocity-time histories at specific locations along the floor.

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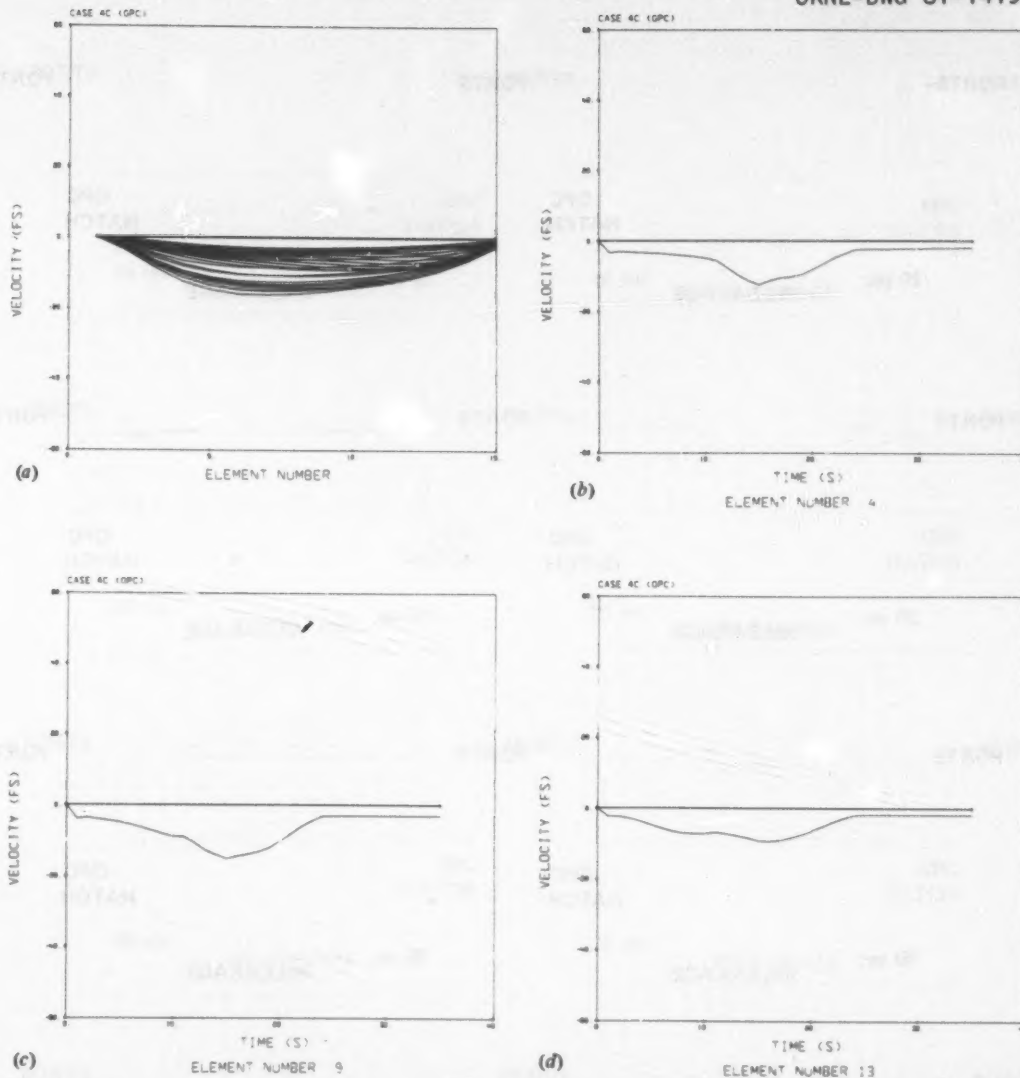


Fig. 6.8. Transient velocities along floor of general-purpose cell for case 4C, 300-mph tornado. (a) Composite of all velocity vs time curves; (b-d) velocity-time histories at specific locations along the floor.

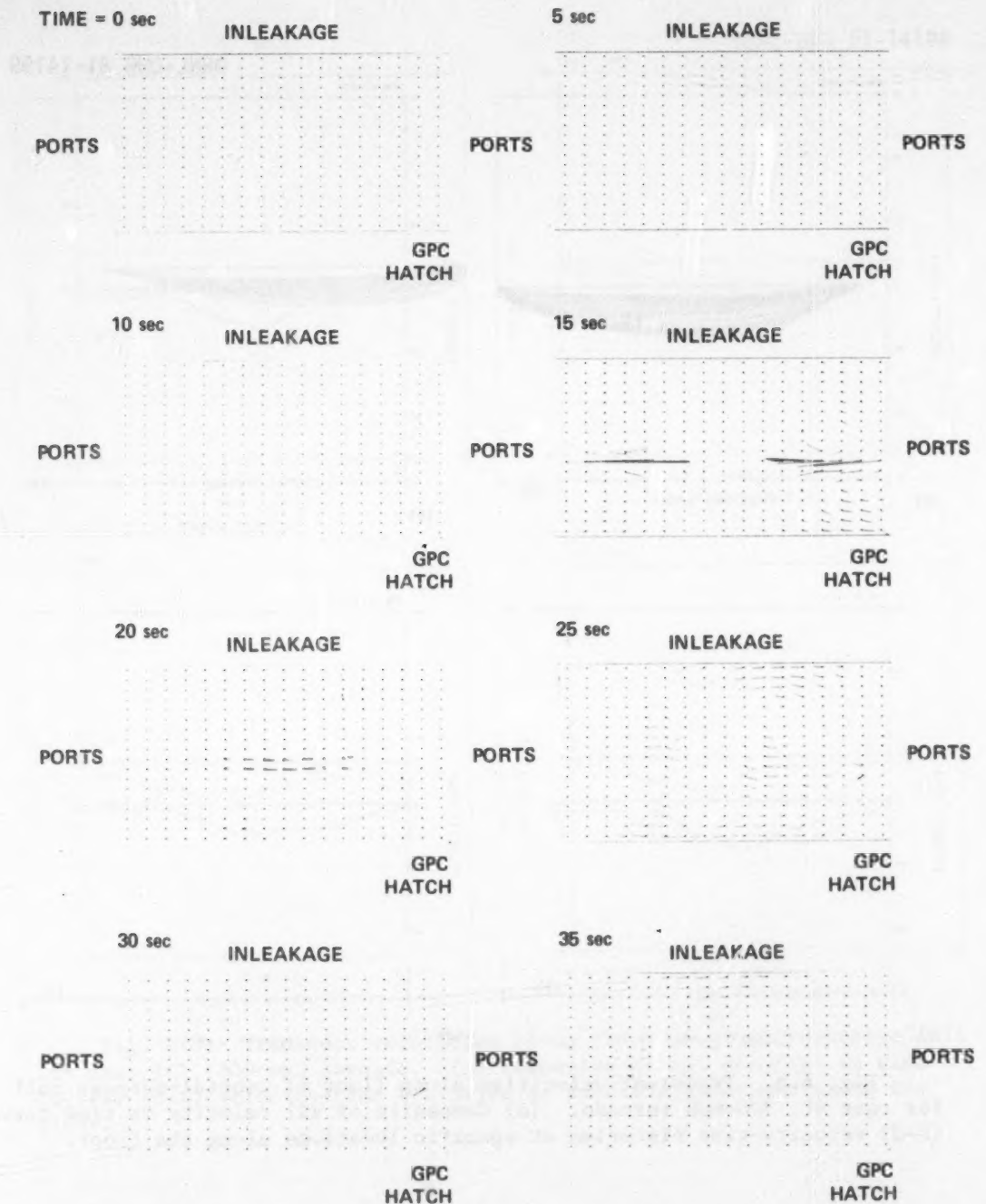
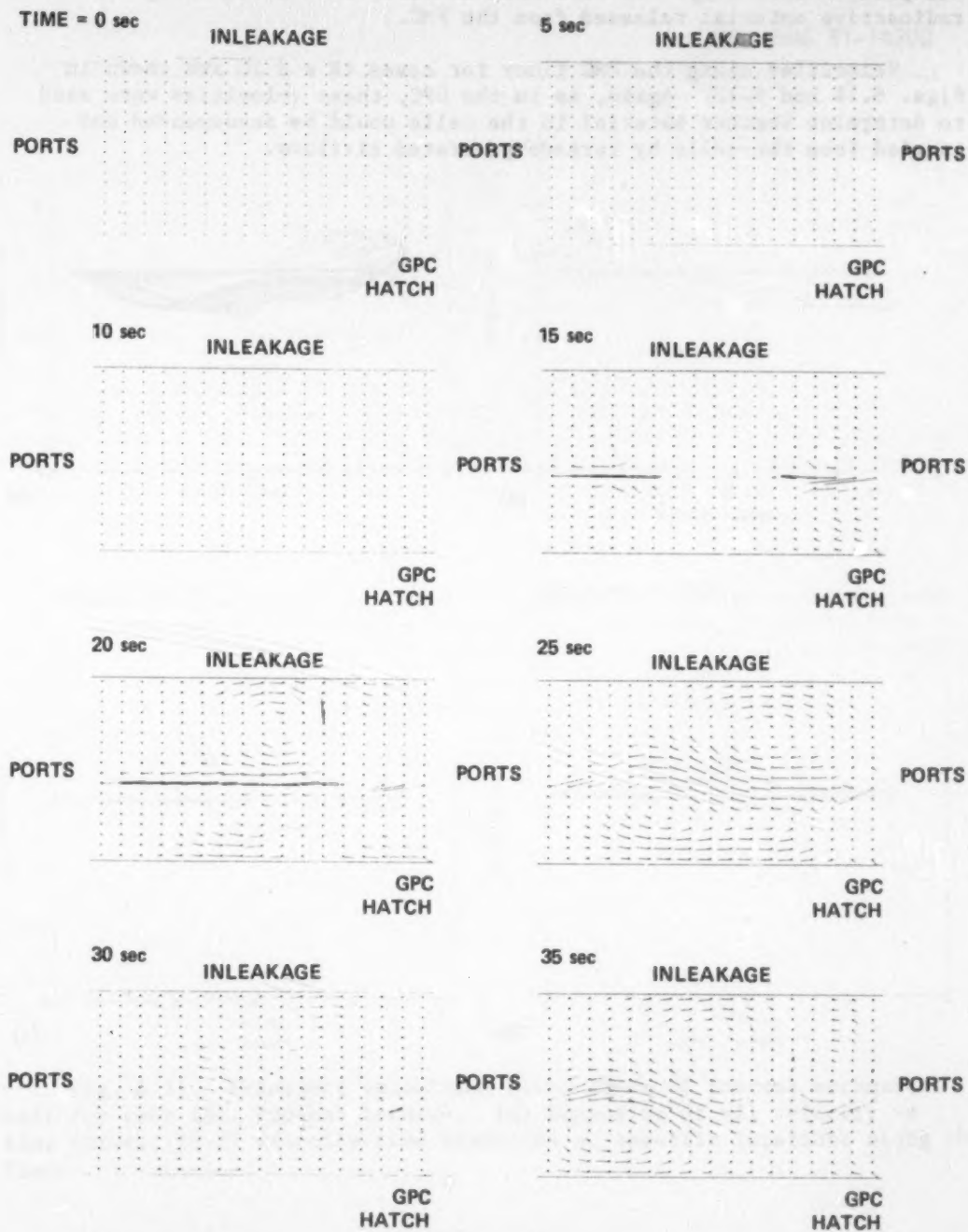


Fig. 6.9. Plots of velocity vectors through process mechanical cell for case 1A1, 100-mph tornado, as determined with SOLA-ICE. (Normal conditions from 0 to 10 s; tornado impact at 10 s.)



the ports. This shape was also used in Part II in determining radioactive material released from the PMC.

Velocities along the PMC floor for cases 1B and 1C are shown in Figs. 6.11 and 6.12. Again, as in the GPC, these velocities were used to determine whether material in the cells would be resuspended and carried from the cells by tornado-generated airflows.

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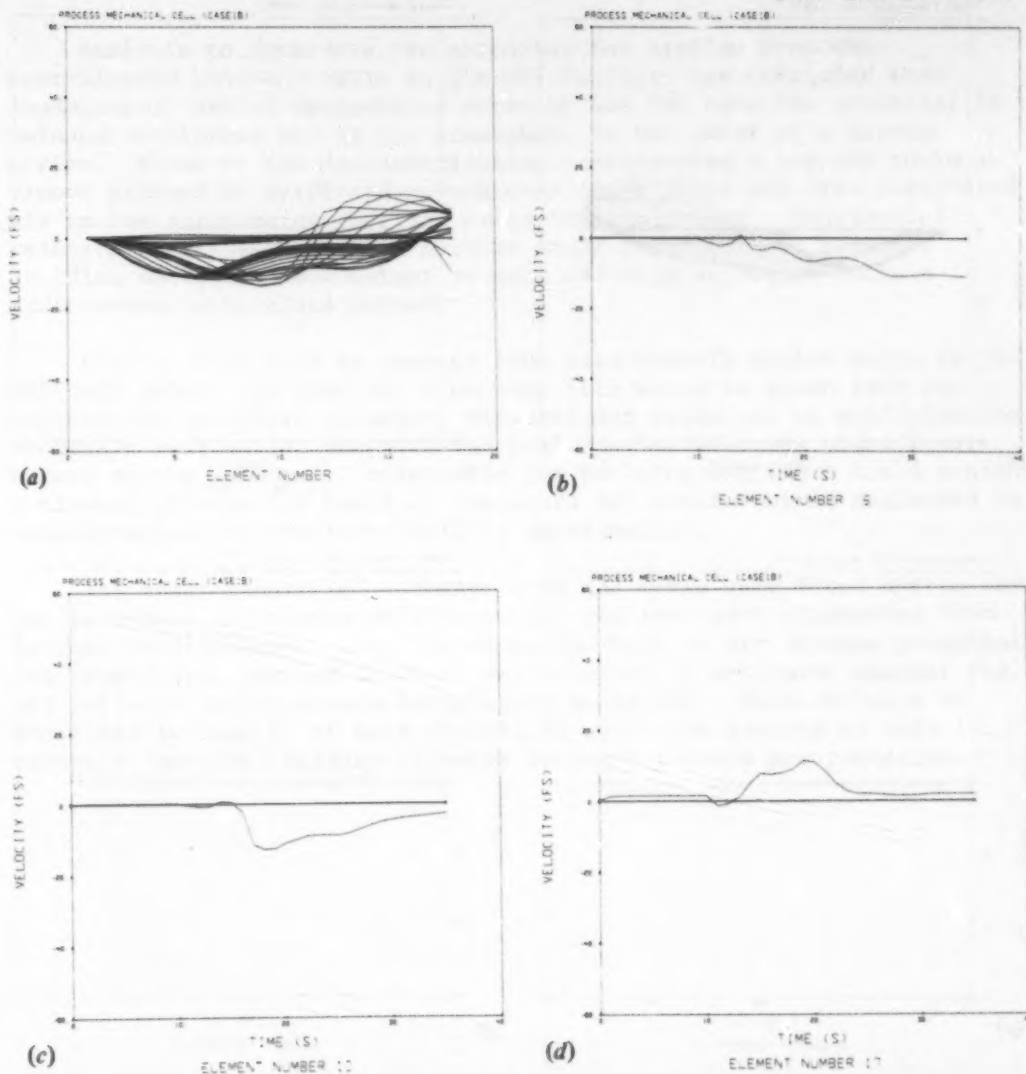


Fig. 6.11. Transient velocities along floor of process mechanical cell for case 1B1, 200-mph tornado. (a) Composite of all velocity vs time curves; (b-d) velocity-time histories at specific locations along the floor.

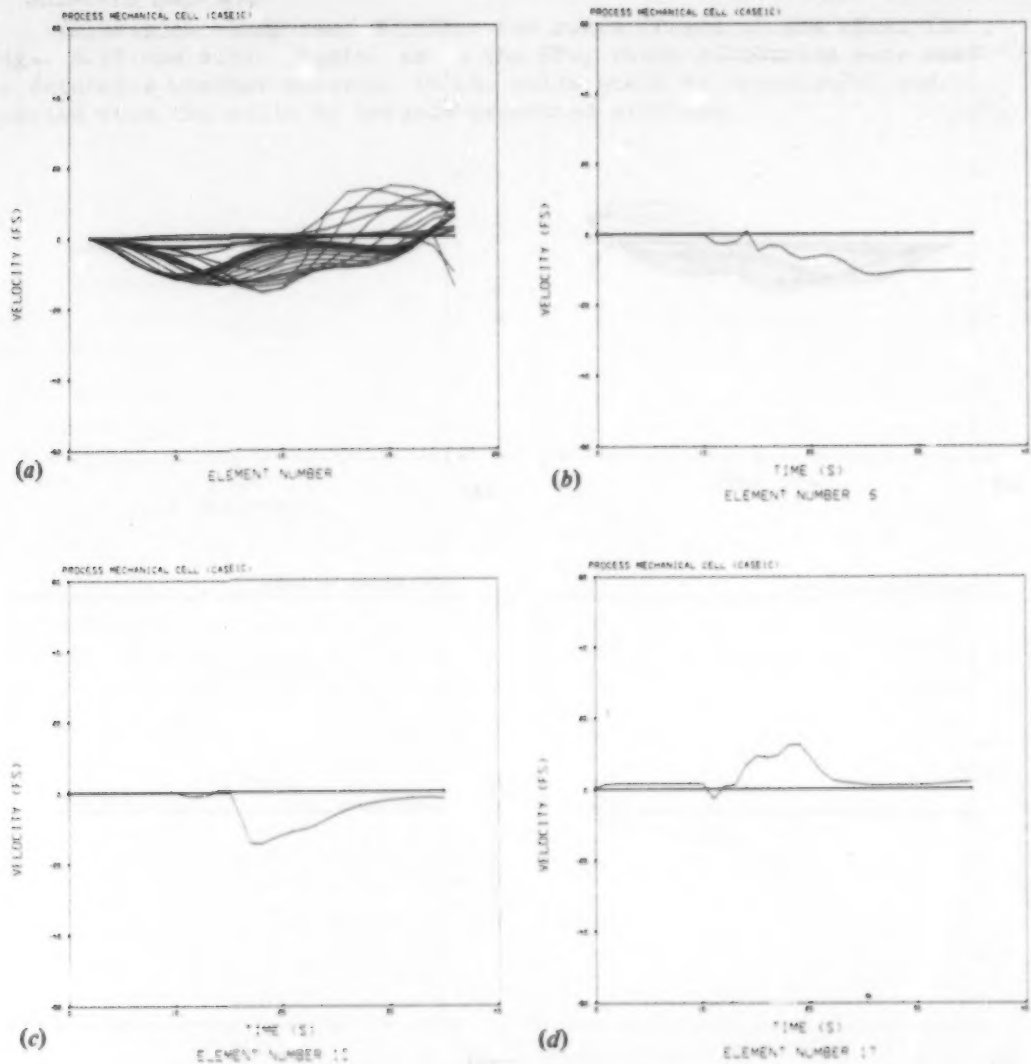


Fig. 6.12. Transient velocities along floor of process mechanical cell for case 1C1, 300-mph tornado. (a) Composite of all velocity vs time curves; (b-d) velocity-time histories at specific locations along the floor.

7. CONCLUSIONS

Analysis to determine the potential for airflow from the contaminated head-end cells in the NFS facility has concluded that inadequately sealed manipulator ports in the PMC have the potential to release unfiltered air to the atmosphere in the event of a tornado strike. Winds or the depressurization accompanying a tornado could remove plywood or cardboard covers over these ports and draw unfiltered air to the surrounding corridor or to the atmosphere. Substantial releases of air through this pathway would occur whether exterior building walls remained intact or not, and this air could contain radioactive particulate matter.

Covers would also be removed from inadequately sealed ports in the GPC cell walls, and some air from this cell would be drawn into the surrounding corridor. However, this release would not be sufficient to reentrain radioactive material and would not present any significant hazard to the public. A release to the building corridors could present a cleanup problem for facility operators and should not be neglected in considerations of possible facility improvements.

The other identified pathways from the cells were found not to have the potential to release unfiltered air and thus were eliminated from further consideration. For the cases in which an air release potential was identified, further analysis was required to determine whether the air released would contain radioactive materials. This analysis is described in Part II of this report, in which the amounts of material released from cell airflow pathways during a tornado are predicted.

1. CONCLUSIONS

The results of the present study are in line with those of other workers who have reported that the rate of growth of the embryo is directly related to the rate of change in the rate of growth of the embryo. The results of the present study are in line with those of other workers who have reported that the rate of growth of the embryo is directly related to the rate of change in the rate of growth of the embryo.

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*Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC 20555 and/or the National Technical Information Service, Springfield, VA 22161.

Appendix A

DESCRIPTION OF TVENT

TVENT is a FORTRAN IV digital computer program developed by R. W. Andrae, K. H. Duerre, and W. S. Gregory of Los Alamos Scientific Laboratory to predict the response of ventilation systems to tornado-generated depressurization areas. TVENT provides the analyst with the capability of determining steady state and transient pressure distributions and of calculating system flows in complex ventilation networks.

The code was written for a CDC computer but is designed to be easily transferred from one computer to another with a minimum of change. Replacing seven source statements in the CDC version with nine source statements for other versions (IBM, Xerox, etc.) makes the conversion straightforward. The code occupies less than 150 K bytes on the IBM 360 at ORNL and is relatively inexpensive to run.

TVENT is documented with a user's manual⁵ and is available from the Argonne Code Center. The code was not verified during this job because of time limitations and primarily because data for verification of TVENT predictions are not available. Several test problems documented in ref. 5 were analyzed using TVENT, and the results gave good agreement with the same problems analyzed by LASL staff. The flow-dynamic algorithms, that is, the flow, pressure, friction, and capacitance relationships, used in TVENT are all well-accepted approximations, and documentation supporting these approximations can be found in the literature. Only their use in a transient situation remains unverified. Correlation tests of this nature are in progress at LASL, but it is still too early to evaluate their results.

TVENT is based on the following assumptions: one-dimensional, isothermal flow; a "lumped" parameter approximation that neglects spatial distribution of variables; and incompressible flow with fluid storage at the nodes. The lumped parameter approach includes a number of system elements or branches joined together at the upstream and downstream ends by connection points called nodes. The pressure variable of the system is lumped at the nodes. Air cleaning system components such as dampers, filters, and blowers that have a resistive nature are located within the branches of the system. The ventilation system duct work represented in the system model as a branch without a component also has a resistive nature, and this frictional resistance to flow is lumped with that for the system components in the branches of the network.

The compressibility of the system is accounted for at nodal points by permitting storage of fluid at these points. Points within a structure with relatively large volumes, such as rooms, cells, globe boxes, or duct plenums, are represented as nodal points where

accumulation of fluid mass is allowed. The general fluid dynamic equations upon which TVENT is based are evaluated on an order-of-magnitude basis, which indicates that the effects of inertia and shock can be neglected for Mach numbers significantly less than 1.

Output from TVENT is organized so that the analyst can easily determine the effects of a pressure transient on components of a system and can check the value of pressure differentials between containment areas for possible loss of confinement integrity. The code also generates line printer plots of selected pressures and flows. In order to facilitate reading of the plots and to generate plots suitable for publication, TVENT has been modified to output a file of point pairs for plotting predicted pressure and flow transients. A plotting package, TPLLOT, was written which uses the ORNL plotting software, DISSPLA, to generate pen and ink plots on the CALCOMP plotter.

Some problems were encountered with convergence when using TVENT for analysis of cases involving steep pressure gradients, in particular, for the 300 mph tornado. The numerical solution techniques selected for TVENT are susceptible to instabilities that can lead to a divergent solution. This is not a serious problem, providing certain precautions are observed to avoid this situation. Historically, any iterative scheme such as this suffers in the same way. When TVENT encounters a solution with a numerical instability, it aborts, of course, but first prints a diagnostic message suggesting minor changes to the model that could avoid this condition. No TVENT problem has yet been found that could not be solved. In most cases the problems were alleviated by switching node numberings across the blowers or by adding a room at the node where the problem occurred. Switching node numbers did not alter the solution results but did facilitate the solution technique. When a room was added, the volumes were so small that results were not significantly affected; however, instabilities were alleviated.

Several cases were analyzed using a smoothed tornado forcing function (no sharp changes in slope) in an attempt to remove sharp variations in the flow rate curves. The altered forcing function did not appear to affect the results, and again, peaks in the flow rate curves were attributed to instabilities introduced to the system by model characteristic alterations.

Appendix B

DETAILED ANALYTICAL TECHNIQUES

In view of the fact that the TVENT code was developed primarily for modeling ventilation systems and components rather than the system of interconnecting volumes and pathways analyzed in this study, it was necessary to develop special techniques to properly model the NFS cell exhaust system. Most of these techniques were suggested by or discussed with authors of the code.

In performing the "worst case" analysis, it was necessary to simulate complete loss of the exterior walls and doors of the building at tornado impact. To avoid the necessity for generating a separate system model for this case, the original schematic model (Fig. B.1) was modified to reflect exterior wall loss. This simulation was accomplished by the following steps:

1. steady state analysis of the cell exhaust model (Fig. B.1) with normal operating system pressures and flows to establish normal branch resistances;
2. generation of a restart deck of system pressures, flows and resistances at completion of steady state analysis;
3. alteration in nodes considered to be boundary nodes in the model to simulate loss of exterior walls; that is, nodes 2, 6, 9, and 10 were changed to boundary nodes in addition to nodes 1, 5, 8, 20, 21, and 25, and the rooms at nodes 2, 6, 9, and 10 were removed;
4. transient analysis with the tornado pressure function applied at interior boundary nodes, 2, 6, and 10, while other boundary nodes remain at atmospheric pressure.

The most significant assumption associated with this procedure is that the building walls and doors are destroyed at the instant of tornado impact. This is a conservative but necessary assumption, since structural analysis of the building was not performed to determine whether the walls would fail.

Another modeling technique required for this study was a method for simulating the dislodging of plywood and cardboard covers over manipulator ports in the PMC and the GPC during the tornado-induced depressurization event. It was determined that a pressure differential across the covers of 0.4 in. H₂O (0.014 psi, cell pressure positive relative to surroundings) was necessary to dislodge the covers during the pressure transient. The 0.4 in. H₂O value is based on the estimate that the force required to remove a cover taped to the cell wall is approximately 2 lb. It was assumed that all of the manipulator covers in



the PMC would dislodge at the same instant, since the pressure differential across each cover would be the same. The 0.4 in. H₂O pressure differential would also be required to remove the covers from ports into the GPC.

Before the tornado reaches the facility, the cells are held at a negative pressure with respect to the surroundings. It is not until a depressurization area created by the tornado passes across the facility that the cell pressure can become positive relative to the surroundings, causing cover dislodgement. Thus the covers would be dislodged at some time during the transient analysis of the system. The capability for altering the model during a transient analysis was not available with TVENT; so a restart procedure was used to make the required alterations. Steps in the procedure are as follows:

1. assign a very low flow (10 cfm) to branches 3, 10, and 11, (manipulator ports into the PMC and the GPC and fire protection duct into the GPC) to simulate the ports with covers intact;
2. run a steady state and transient analysis of this system, using TVENT;
3. from the pressure differential across the ports during the transient analysis (ΔP between nodes 3 and 2 and between nodes 4 and 10), determine the time at which the pressure differential across the covers reaches 0.4 in. H₂O (cell pressure positive relative to surroundings); at this time the covers should be dislodged;
4. run a steady-state and transient analysis of the same system with 10 cfm flow in branches 3, 10, and 11, but stop the transient at the time (determined from step 3) at which the covers are dislodged and generate a restart deck;
5. change (lower) the resistances for branches 3, 10, and 11 in the restart deck to simulate loss of the covers;
6. restart and continue the transient analysis with covers now removed.

In step 3, it was determined that the manipulator covers over ports in the PMC (branch 3) would be dislodged 2.7 s after the tornado strike for case 1A, 0.9 s for case 1B, and 0.6 s for case 1C. The covers in branch 11 (manipulators into the GPC) would dislodge 1 or 2 s later for each case, and the cover in branch 10 (the fire protection duct to the GPC) would never be dislodged. It is not possible to stop and restart a problem twice with TVENT, so the conservative assumption was made that the covers in branch 11 would be dislodged at the same instant as those in branch 3.

Using this procedure for cases 2 and 4, it was found that the covers would not be dislodged during the transient. For case 3, with manipulator ports into the PMC sealed, the cover in branch 11 would be dislodged but not the cover in branch 10 as long as the building exterior

walls were intact. With the building exterior walls destroyed, both covers would be dislodged. With the exception of cases involving the 100-mph tornado, in which the covers dislodge after 2 to 3 s, in most of the cases analyzed, results would not be significantly affected by assuming that the covers would dislodge at the start of the transient. This assumption would substantially reduce the number of steps in this procedure.

In analyzing case 4, the pathway from the GPC exhaust duct to the atmosphere through the destroyed MSM building, it was necessary to simulate loss of the MSM building walls. The procedure discussed previously to simulate loss of the main process building walls was used for this case. After the steady state analysis with generation of a restart deck, nodes 22, 23, and 24 were changed to boundary nodes, and the tornado pressure function was applied at node 24. Again, the conservative assumption was made that the MSM building walls would be destroyed at the instant of tornado impact. This assumption was not supported by a structural analysis of the building.

One final modeling technique used in analyzing the NFS facility involved Case 2, the pathway from the CPC through the EDR to the atmosphere. Examination of the cell configuration block diagram shown previously (Fig. 3.3) reveals several potential release pathways from the CPC to the environment. Air could flow from the CPC through an adjoining crane room to the chemical operating aisle and outside. Another flow pathway would be from the CPC through the adjoining scrap removal room to the atmosphere. Air could also travel from the CPC through the EDR to the outside. Instead of generating a detailed model including all of these pathways, each pathway was analyzed separately to determine which had the least resistance to airflow. The pathway with least resistance would be the path through which air would tend to flow out of the facility, and this pathway was determined to be through the EDR to the atmosphere. Resistances in the other pathways were at least twice as large as resistance in the EDR path. The other two paths were eliminated from consideration, and the model was simplified with the assumption that all airflow would be through the EDR to the outside.

In each of the described modeling techniques, the purpose was to simplify the analysis with conservative assumptions while still modeling the system as realistically as possible.

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NUCLEAR FUEL SERVICES' WEST VALLEY FUEL REPROCESSING PLANT

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